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The Translators provide Z-8000 source code from Intel 8080 or Zilog Z-80 source code. The Z-8000 source code used by these packages are the unique 2500AD syntax using Zilog mnemonics, designed to make the transition from Z-80 code writing to Z-8000 easy.

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Cross reference table generated—

Plain English Error Messages—

System requirements for all programs: Z-80 CP/M 2.2 System with 54k TPA and at least a 96 column printer is recommended. Or 8086/88 256k CP/M-86 or MSDOS (PCDOS).

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-----8086 and Z-8000 XASM includes Source Code Translators-----

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Z-8000™ ASM		750.00			299.50
Z-8000 XASM	199.50		199.50	199.50	
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Z-80 ASM	49.50				
Z-80 XASM		500.00	99.50	99.50	99.50
Z-8 XASM	99.50	500.00	99.50	99.50	99.50
6301(CMOS) <i>new</i>	99.50	500.00	99.50	99.50	99.50
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6502 XASM	99.50	500.00	99.50	99.50	99.50
65CO2(CMOS) XASM <i>new</i>	99.50	500.00	99.50	99.50	99.50
6800,2,8 XASM	99.50	500.00	99.50	99.50	99.50
6801,03 XASM	99.50	500.00	99.50	99.50	99.50
6804 XASM <i>new</i>	99.50	500.00	99.50	99.50	99.50
6805 XASM	99.50	500.00	99.50	99.50	99.50
6809 XASM	99.50	500.00	99.50	99.50	99.50
8748 XASM	99.50	500.00	99.50	99.50	99.50
8051 XASM	99.50	500.00	99.50	99.50	99.50
8080 XASM	99.50	500.00	99.50	99.50	99.50
8085 XASM	99.50	500.00	99.50	99.50	99.50
8096 XASM <i>new</i>	99.50	500.00	99.50	99.50	99.50
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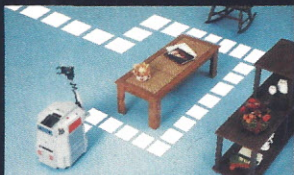


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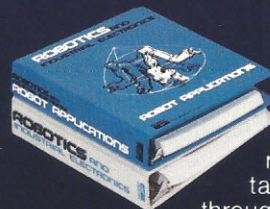
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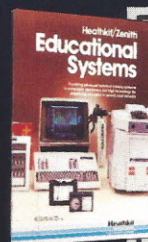
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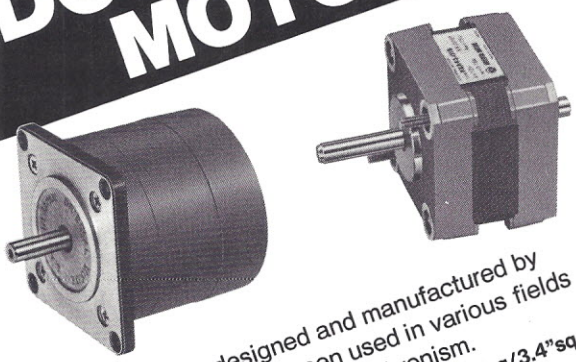
42 New Products



About the cover: Robots are entering the educational marketplace from preschool through advanced graduate education and research. Not all of the robots are being used to teach robotics. Just as computers are used to teach other courses as well as computer programming and design, so are robots used to teach basic principles such as problem-solving and elementary mathematics, and more advanced topics such as mechanics and real-time design.

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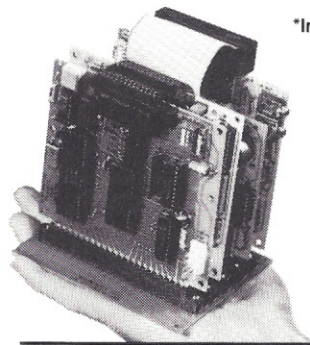
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Editorial

ROBOTIC EDUCATION AND ITS SHORTCOMINGS

Guest Editorial by

Geary V. Soska, CMfgE
Midwest Regional Manager
Cybotech Corp.
Indianapolis, IN

Industrial robots have been in use since the early sixties. Yet only in the past six years has any *real* emphasis been placed on the need for formal training. Unfortunately, the majority of colleges and universities, as well as community colleges and vocational-technical schools, really missed the boat trying to address this need.

Today, many colleges and universities offer some kind of course in robotics. Some even have robots to give students hands-on experience. If you visit these colleges and universities, however, you will find that in most cases the equipment is not representative of current technology. You will find that these institutions concentrate almost *exclusively* on design and theoretical research, and do not teach students how robot technology can be applied to ensure American competitiveness and survival in the world marketplace.

In addition, at most colleges and universities, any meaningful work done with robotic equipment is at the graduate level. What a fantastic educational opportunity for undergraduate students!

Problems also appear at community colleges and vo-tech schools. Between the news media hypes and the Wall Street forecasts that the American robot industry will grow to a \$2 billion industry by 1990 (20,000 robots if you assume the average price of a robot system is around \$100,000) these institutions have convinced themselves that industry will need an army of robot technicians to care for all those new robots.

There are about 7,000 robots in use in the United States. Approximately 60 percent of them are at work building automobiles. Since it took over 20 years to put some 7,000 robots to work across the United States, it is unlikely that another 20,000 robots will be put to work over the next six years. And even if we could put another 20,000 robots to work by 1990, each robot certainly doesn't need its own *personal* technician.

When this point is brought up to the community col-

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5 Decade of Robotics
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leges and vo-tech schools, they all offer about the same defensive response: "We'll need technicians to install the robots. We'll need technicians to maintain the robots. We'll need technicians to troubleshoot and repair them. We'll need technicians to operate them. We'll need technicians to program them."

These community schools fail to realize that in the heavily industrialized areas of this country, where the greatest concentration of robots exists, most of the so-called robot technician tasks (with the exception of operating the robots, which is assigned to the person displaced by the robot) are performed by various skilled-trades personnel.

Traditionally, community colleges and vo-tech schools have recruited their students primarily from high schools. Unless these students can show proof of eight years of related work experience or a journeyman's card, their chances for employment as robot technicians are mighty

slim. What these institutions really need to do is take their robot technician programs directly to industry where the introduction of robot technology is displacing unskilled and semi-skilled workers, thus creating the need to retrain these people as well as creating the need to upgrade the technical competency of the skilled-trades personnel who work with this technology.

As for colleges and universities, they could best serve the needs of American industry by integrating robotics courses into manufacturing engineering or manufacturing engineering technology degree programs and offering these programs from a practical, applied standpoint, rather than concentrating almost exclusively on design and theoretical research.

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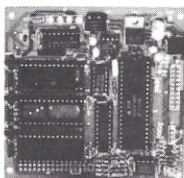
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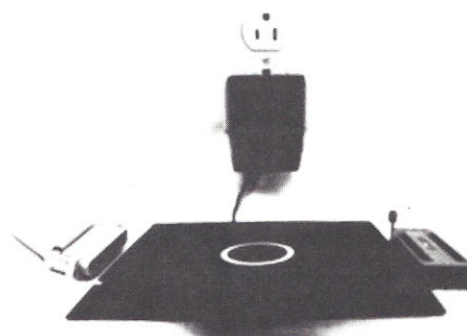
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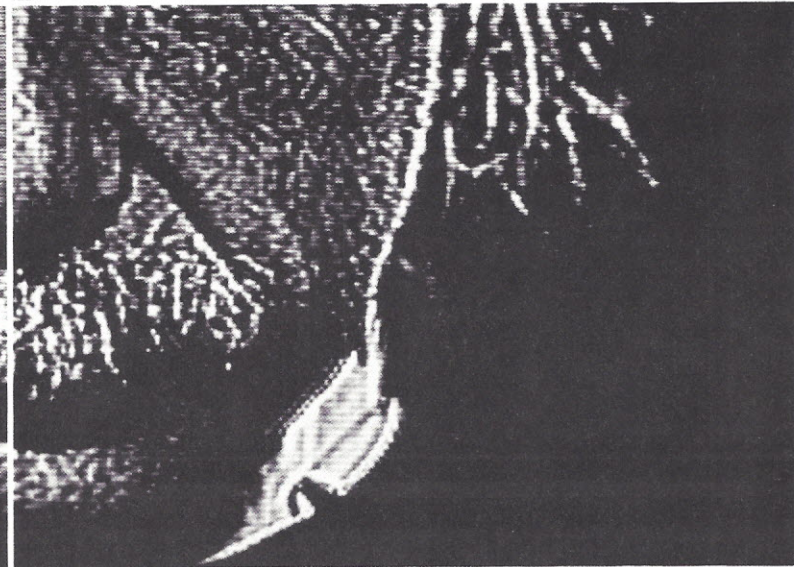


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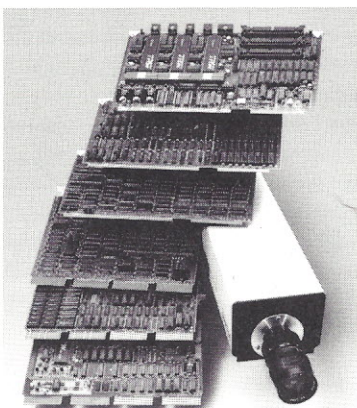
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Panasonic Enters Pana Robo in U.S.

NEW YORK—Panasonic, the Japanese electronics giant, has announced that it will enter the U.S. market with its new line of industrial robots, the Pana Robo. The company says the robots are designed for use in a wide range of manufacturing applications, from assembly to welding. The robots are said to be more flexible and easier to program than other industrial robots on the market. Panasonic is currently testing the robots in its U.S. facilities and expects to begin selling them in the near future.



Toyoda Regains Machining Ctr's

NEW YORK—Toyoda Machine Works, a Japanese manufacturing company, has announced that it has regained control of its U.S. machining centers. The company had previously lost control of these centers to a group of investors, but has now successfully reclaimed them. Toyoda says it plans to continue its operations in the U.S. and to expand its production capabilities.



IR/1 P256 Building Block For GMF Vision System

NEW YORK—The IR/1 P256 Building Block is a new component for the GMF Vision System. It is designed to provide a more accurate and reliable vision system for industrial robots. The component is said to be easy to install and use, and is expected to be a popular addition to the GMF Vision System.

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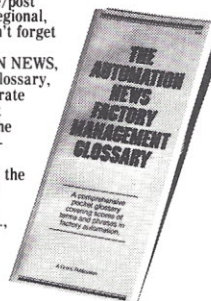
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Calendar

SEPTEMBER

10-13 September. 10th Annual Advanced Control Conference. Fowler Hall, Stewart Center, Purdue University, West Lafayette, IN. Contact: Edward J. Kompass, Control Engineering Magazine, 1301 South Grove Ave., PO Box 1030, Barrington, IL 60010, telephone (312) 381-1840.

This year's conference celebrates the 25th anniversary of the application of digital computers to industrial control. Twenty-two applications papers will support the four specially commissioned, two-hour tutorials. Topics include: a view of the beginnings and development of computer-based industrial control, the merging of discrete and continuous process control, the beginnings of computer-based digital control systems, and a future scenario for computer-based digital control systems. Applications papers cover: array processors, fiber optic data buses, micro and personal computer packaging for industrial applications, personal computer software packages for industrial control, industrial I/O for personal computers and the role of humans in fully computerized industrial plants.

14-16 September. Heart of Texas Computer Show. Bayfront Plaza, Corpus Christi, TX. Contact: Heart of Texas Computer Show, PO Box 12094, San Antonio, TX 78212, telephone (512) 681-2248.

Vendors will display the latest in small business and personal computer systems, with robots, games, and other high-tech products. Educational seminars are also planned.

24-26 September. Robotics Seminar. IEE Education Center, Technology Park/Atlanta, Norcross, GA. Contact: Institute of Industrial Engineers, Conference Department, 25 Technology Park/Atlanta, Norcross, GA 30092, telephone (404) 449-0460.

The Robotics Seminar will acquaint participants with the variety of equipment available and how and where robots might be used effectively. Special seminar features include a full-day laboratory experience where participants can see robots in action and a workshop session for discussing and analyzing potential robot applications.

25-26 September. NASA Symposium on Productivity and Quality: Strategies for Improving Operations in Government and Industry. Capital Hilton Hotel, Washington, DC. Contact: Pamela Edwards, AIAA, telephone (212) 581-4300.

The symposium is sponsored by NASA and organized and operated by AIAA.

25-27 September. International Industrial Controls Conference and Exposition (IIC '84). Philadelphia Civic Center, Philadelphia, PA. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

Preliminary session titles include: *Advances in Information Flow Networks; Highways for Factory Automation; Vision; User-Friendly Software for Programmable Controllers; Fiber Optics; and Robotics.*

OCTOBER

2-4 October. 14th International Symposium on Industrial Robots. Gothenburg, Sweden. Contact: Swedish Trade Office, 4000 Town Center, Suite 202, Southfield, MI 48075, telephone (313) 352-6990.

Close to 1,000 delegates are expected to participate in this year's symposium. In connection with the symposium, there will also be an extensive international exhibition showing the latest developments and achievements in the field of industrial robots.

2-4 October. AUTOFACT 6. Anaheim Convention Center, Anaheim, CA. Contact: Gregg Balko, Computer and Automated Systems Association of SME, One SME Drive, PO Box 930, Dearborn, MI 48121, telephone (313) 271-1500.

AUTOFACT 6 will feature a comprehensive program of tutorials and conference sessions covering the entire spectrum of computer-integrated manufacturing, from design and engineering, through fabrication, assembly, inspection and testing, to shipping.

2-5 October. Robot 84, Scanautomatic 84, and The 14th International Symposium on Industrial Robots. Gothenburg, Sweden. Contact: Swedish Trade Fairs Foundation, Box 5222, S-402 24 Goteborg, SWEDEN, telephone 46 31 20 00 00.

Three major international events devoted to the design, production, and uses of industrial robots will take place in the Swedish Trade Fair halls simultaneously in October. Robot 84 is an international exhibition of industrial robots and control systems for materials handling, assembly, and complex production tasks. Scanautomatic 84 covers industrial computers and the pneumatic, hydraulic, and electronic components which provide the backup technology for industrial automation. The Symposium on Industrial Robots is organized jointly by the Swedish Trade Council, the Swedish Trade Fairs Foundation, and MEKAN, Sweden's largest industrial association.

Calendar

ACM-84, The Fifth Generation Challenge. San Francisco Hilton, San Francisco, CA. Contact: ACM-84, PO Box 32575, San Jose, CA 95152, telephone (415) 948-6306.

The Japanese Fifth Generation supercomputers pose a challenge to American computer manufacturers, and the ACM-84 Conference topic areas attest to the concern generated by this challenge: supercomputers; developments in artificial intelligence; robotics and sensing; the impact of the fifth generation; limits on technology transfer; applications for the 1990s in business, education, manufacturing, research, and the professions; and anticipated changes in society.

10-12 October. InteRobot-West '84. Long Beach Convention Center, Long Beach, CA. Contact: Tower Conference Management Co., 331 W. Wesley St., Wheaton, IL 60187, telephone (312) 668-8100.

InteRobot-West '84 offers 20 technical conference sessions, three special-interest tutorials, and 80 internationally recognized speakers and session chairmen. Session titles include: *Industry Overview; Tooling Design; Machine Languages; Machine Vision; Machine Sensors; Robots in the Foundry; Personal and Educa-*

tional Robots; Education in Robotics; and Emerging Robot Applications.

25-27 October. Robotics Seminar. IIE Education Center, Technology Park/Atlanta, Norcross, GA. Contact: Institute of Industrial Engineers, Conference Department, 25 Technology Park/Atlanta, Norcross, GA 30092, telephone (404) 449-0460.

The Robotics Seminar is designed to acquaint participants with the variety of equipment available and how and where robots might be used effectively. Special seminar features include a full-day laboratory experience where participants can see robots in action and a workshop session for discussing and analyzing potential robot applications.

NOVEMBER

4-9 November. Intelligent Robots and Computer Vision. Hyatt Regency, Cambridge, MA. Contact: SPIE—The International Society for Optical Engineering, Bellingham, WA 98227-0010, telephone (206) 676-3290.

The emphasis for the 1984 conference is intelligent robots, vision, and sensor systems. The intent of the sessions is to address and inter-

change ideas on a wide range of applications, issues, and techniques for these advanced intelligent systems. State-of-the-art technical design and modern equipment concepts will be presented. Topics to be addressed and for which contributed papers are requested include: government and industrial programs in intelligent sensors and robotics; applications of intelligent sensor systems; statics, kinematics, dynamics, and control of robot systems; standards for sensors and robots; image processing; feature extraction; three-dimensional object representation; use and application of artificial intelligence; and image understanding in intelligent robotics and computer vision.

16-17 November. 6th Annual Forth Convention. Hyatt Palo Alto, Palo Alto, CA. Contact: Forth Interest Group, PO Box 1105, San Carlos, CA 94070, telephone (415) 962-8653.

The Forth Interest Group is a worldwide non-profit organization with more than 4700 members and 53 chapters devoted to the Forth computer language. The convention is prepared to meet the needs of every Forth enthusiast—beginner to professional—with two days of hands-on tutorials, exhibits/vendor booths, lectures, and discussions.

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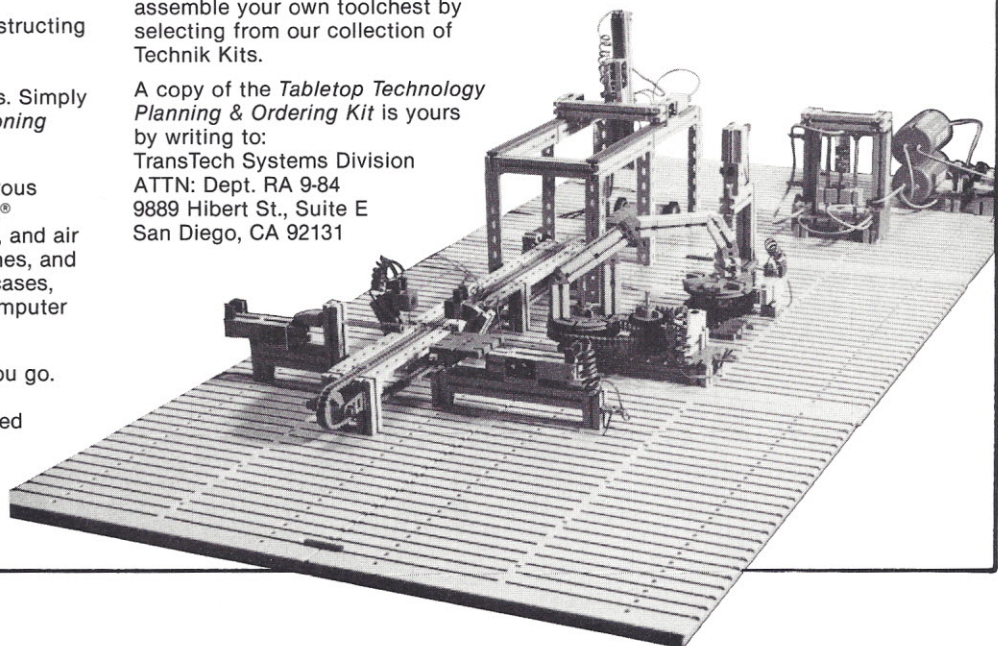
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ROBOT TESTIMONY. For the first time in history, a personal robot testified before members of the US House of Representatives. On May 22, RoPet-HR, manufactured by Personal Robotics Corp., testified before the House Select Committee on Aging, chaired by the honorable Edward Roybal (D-Los Angeles), to demonstrate its safety benefits to the elderly. RoPet-HR showed some of its abilities by detecting a passerby and activating a built-in alarm when it did not receive the correct spoken response, adding that it would soon set off a remote alarm or phone for assistance.

Projected capabilities include detecting the word "Help," dialing the police emergency number, and then homing in on the person and acting as a two-way telephone system. At present, Personal Robotics Corp. is working with the Palo Alto Veterans Administration Hospital on this project and others. For more information, contact: Personal Robotics Corp., 469 Waskow Drive, San Jose, CA 95123.

OLYMPIC RESULTS. More than 15 Southern California schools captured awards at the Robot Olympics held at Cal State, San Bernardino on April 27-28. The games gave students ranging from elementary through high school, an opportunity to demonstrate their computer and robot programming skills. Students programmed such computers as the Big Trak, Turtle Tot, and Hero I, in competitive events including figure tracing and traversing a maze. Student teams raced across the clock to construct a Memocon Crawler robot from a sealed kit against the clock.

Mission Junior High School took the first place trophy in the robot construction event, building a functional robot in 26 minutes and 20 seconds. All schools finishing in other events such as the robot biathlon and robot slalom were awarded trophies. Robot programming events included figure tracing, robot slalom, robot biathlon, and the robot dash.

FORT WORTH RESEARCH CENTER. Business and civic leaders have begun a campaign to raise \$10 million in funding to create the Advanced Robotics Research Institute, a high-tech center to be located in Fort Worth and staffed by the engineering department of the University of Texas at Arlington.

The Institute will provide a center for research into practical applications for the newly-emerging science of robotics and artificial intelligence. In addition to studying new areas of application, the engineering team will work with robotics manufacturers and plant owners who use equipment to increase productivity. The staff of robotics experts has been assembled by Dr. John W. Rouse, dean of the UTA School of Engineering, and will be supplemented with visiting professors as well. The building is scheduled for completion in 1985.

TRAINING REPORT. The Center for Occupational Research and Development (CORD) has completed preparation of a state-of-the-art report describing current training of robotics/automated systems technicians in the United States. The report includes listings of two-year post-secondary schools that offer robotics/automated systems technician training, those schools with baccalaureate and graduate training in robotics, and a list of texts currently in use at the various schools. Also included is a needs assessment of programs and materials required to adequately train technicians to operate and maintain tomorrow's robots and automated systems. The report is available from CORD, 601C Lake Air Drive, Waco, TX 76710.

NBS AND WESTINGHOUSE JOIN FORCES.

The National Bureau of Standards and Westinghouse R&D Center are beginning a joint research program to study robot control techniques capable of managing a robot for close-tolerance parts-matching and for work in concert with a second robot. The project will be based on NBS-developed real-time control systems for robots. Researchers will work on control systems to be used in an automated parts cleaning and deburring station in the NBS Automated Manufacturing Research Facility. This work station will feature the cooperative action of two robot arms working under a common system.

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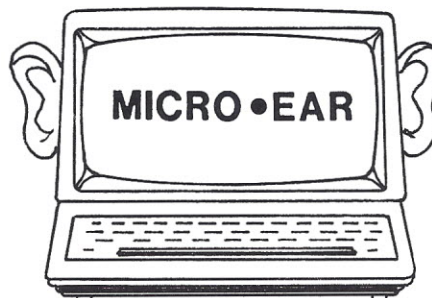
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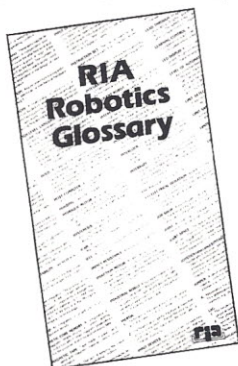
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Sensory Perceptions

workings of a robot to your friends, keep an eye out for Robot Odyssey I, an educational program aimed at teenagers and young adults. Announced at the Consumer Electronics Show in Chicago, Robot Odyssey is a game which claims to teach players the basics of digital electronics, including designing circuitry that controls robots.

Players begin by falling into Robotropolis, a futuristic underground city inhabited by robots. They must then escape and return to civilization by constructing a robot that helps players work upward through several levels. Each level has new obstacles and antagonists that require robots with different skills. As players get closer to civilization, escape becomes increasingly difficult.

The robots are designed in the Innovation Lab, which is equipped with a tool kit for designing robot circuitry, a prototype chip, three robots to use for experimentation, a room for creating new chips, and a library to store chips with special capabilities. In the course of robot design, players design circuits from simulated wires and logic elements, discover the basic principles behind programming and debugging, and learn about Boolean operations.

Robot Odyssey is published by The Learning Company, 545 Middlefield Rd., Suite 170, Menlo Park, CA 94025.

LABORATORY ROBOTICS STUDY. Strategic Directions International, Inc. has announced a major multiclient study on laboratory robotics that will cover the United States, Western Europe, and Japan. The study will identify actual laboratory robotics requirements, present and future (1984-1990), and survey the present and future involvement of the robotics, computer, instrument, and laboratory equipment manufacturers. Industrial, clinical, and biological laboratories are covered. The study is a technology, market, and opportunity assessment that will be of planning value to the laboratory managers and various involved manufacturers. Laboratory robotics differs from industrial robotics in many respects: size, required sensors, interface demands to instruments, computers, other lab equipment, and even the process itself. Those human functions of the laboratory that can be robotized with a significant return on the investment will be identified. The developing demand will be quantified and projected through 1990 in various segmentations.

For a detailed prospectus, contact Strategic Directions International, Inc., 9841 Airport Blvd., Suite 806, Los Angeles, CA 90045.

TRAINING MODULES. The PZ-80 Micom series modules represent a comprehensive training program complete with hands-on experiments in digital circuitry, computer logic, robotics, and data transmission. The kit contains a training and instructional manual, power supply, and 42 modules that take the user from the basics through applications that include a micro-controlled optical interrupter to measure RPM and establish motor control, a fully programmable music synthesizer, and a digital clock that employs real-time microprocessor controls. It provides hands-on training for the engineer who wishes to update his knowledge, or serves as an excellent training vehicle for the company wishing to enhance the knowledge of its technicians.

Each of the small boards supplies a training lesson exploring one facet of digital circuitry. For example, one board contains a RAM chip—with it the user learns how to address the chip, write information, and read information. Another module teaches the user how to control a digital display. Yet another teaches the user to use one-shots.

A preliminary copy of the training manual reveals in-depth coverage of electronics and electronic control. The manual is divided into three logical sections: Basic, Practical, and Application. The Basic section presents the theory behind most module components and describes their use. The Practical section builds upon these basics and starts to use the Z80 microprocessor board. Here, the emphasis is on basic programming techniques for control. Users learn to program lamps, read switches, and perform basic computations. The third section, Application, shows the user how to build and control such items as a melody module, amplifier, optical switch, DC motor control, digital-to-analog converter, temperature sensor, and a one-chip microcomputer digital temperature controller.

Additional accessories are available for advanced learning and practical experimentation. These accessories include robot arms, automatic drilling machines, EPROM writers, voice, printer, music, and fiber optic communication modules.

The PZ-80 Micom module kit sells for \$599. Accessories range in price from \$19 for the small printed circuit boards to \$1495 for the robot arm.

For more information, contact: Frank Kaplan, Compusa Corp., 1101 Bristol Rd., Mountainside, NJ 07092, telephone (201) 654-7220.

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An Introduction to Robot Technology

By Philippe Coiffet and Michael Chirouse

Aimed at the engineering and computer professional, this book combines electronics and mechanical engineering topics to provide a practical introduction to the basic principles and concepts of robotics. Numerous mathematical models, diagrams, and appendices illustrate typical robot design considerations along with individual components such as controls, motors, actuators, and sensors. Emphasizing applied concepts as well as theoretical, the book also includes chapters on the computer control, characteristic properties, usage, "training," and real-world applications of robots.

6 1/2 x 9 1/4 208 pp. 60 illus.

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Computers in Manufacturing Principles and Practices for Managers and Engineers in Metalworking

Edited by the Staff of American Machinist

This book was developed to meet the information needs of executives, managers, and engineers - both manufacturing and design - who are responsible for efficient performance and productivity in metal products industries. It presents a comprehensive overview of the computer's role in modern metalworking.

The book covers computer integrated manufacturing (CIM); design for products and tools; graphics; computer simulation for products, processes, and systems planning; procedures for justifying the investment in computer equipment; and management uses of computers - from mainframes to micros - for planning and control. The new concept of flexible manufacturing systems (FMS) is thoroughly discussed, and several chapters are devoted to specific applications and to case histories for metal cutting, metal forming, assembly, finishing, inspection, and robotics. 3 1/2 x 10 3/4 320 pages. **\$33.95**

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The emphasis is on CNC Systems and their programming capabilities, advantages, operation, and maintenance. Yet, a good portion of the hardware material from past editions has been retained to satisfy those systems still in operation. A wide range of topics covers everything from specific information on plant requirements, to step-by-step economic justification procedures of systems (with tables listing comparative savings versus conventional hardware equipment), to detailed part programming and basic computer operations. The latest in EIA Standards describe updated and standardized tape codes for easy reference.

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By V. Daniel Hunt

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Hunt reveals a wealth of information on foreign research and development in the industry and the companies involved in and exploring the manufacture of industrial robots. He also supplies an extensive list of the various robotic systems, including the potential of "smart robots," grouped into types of models. The list includes important technical information on specific applications pertaining to: tolerances, load carrying capacities, price, and names and addresses of companies and individuals to contact for further information.

1983, 352 pp. (T), illus. **\$32.50 (T)**

Industrial Robotics Handbook provides specific information on:

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Francine Foster
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Creative Learning Systems, Inc.
9889 Hibert Street, Suite E
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Almost everything that is technologically interesting is kept under wraps. Under asphalt and manhole covers lies a network of resource-, power-, and information-bearing arteries most people never see. Inside black boxes are tucked away the controls for vital machinery. Walls and security devices keep workers in one area of a factory from witnessing accomplishments in other areas. The complex interconnections between delivery systems, black boxes, and the various operations that take place in manufacturing facilities are obscured by the vast scale of major enterprises.

Even engineers—who have more opportunities than the average person to understand the inner workings of things—may sometimes have difficulty comprehending technological phenomena outside their immediate purview. Specialization can cause myopia.

Our objective over the past 25 years, first as educators and later as entrepreneurs, has been to make technology more *transparent*: to strip away barriers and broaden vision so that people in a variety of settings can better understand the operational principles behind technological achievements.

As educators we've worked in schools, universities, and research institutions to develop curricula for technology-education programs. As educators and entrepreneurs we've been involved in the design, development, selection, and marketing of instructional materials that advance our mission of making technology transparent.

At TransTech Systems, we are especially interested in promoting hands-on learning about technology—providing for unmediated experiences that synergistically foster

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The Tabletop Technology system allows a person to simulate a whole range of technological contexts. For example, at the larger end of the simulated scale you can construct a model of a pick-and-place arm with several degrees of freedom. Within the

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A smaller-scale robot arm cannot have as many capabilities. But, and this is the key point, at this smaller scale, the arm can function within a larger, more meaningful context. It can function within the context of an automated manufacturing model: it can perform as a member of an orchestrated miniature automated factory.

A sophisticated model of this kind was constructed at the University of Central Florida in the graduate program in industrial engineering directed by Dr. Chris Bauer. Extending over several tabletops, the model simulated a computer-integrated manufacturing (CIM) facility (Photo 1).

Miniature scale-model robots functioned within a process that included sorting small boxes by size, inserting appropriately sized workpieces into the boxes, placing cover plates on the boxes, moving the boxes down a conveyor belt, and loading the boxes onto a truck.

Model electromagnetic components in several of the robots lifted the metallic box covers and workpieces. Fischertechnik photosensors and limit switches reacted to various motions in the process and fed information back to an Apple computer through an ISAAC data acquisition interface. In all, close to 48 inputs and 48 digital single-line outputs were used to monitor and control the model (Photo 2).

Dr. Bauer's group also developed, but never incorporated, a color sensor that could be used in a photocell to generate voltages signifying particular box colors. This addition would have allowed the model to sort components by color as well as by size.

Commenting on his teaching experiences with fischertechnik modeling sets, Dr. Bauer says, "Working with large, full-scale

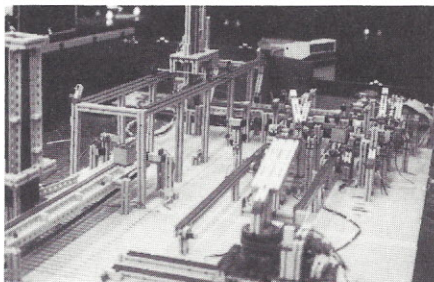


Photo 1. Complex manufacturing plants can be simulated from modular fischertechnik components. This model of a computer-integrated manufacturing (CIM) operation was constructed by the Department of Industrial Engineering at the University of Central Florida in Orlando.

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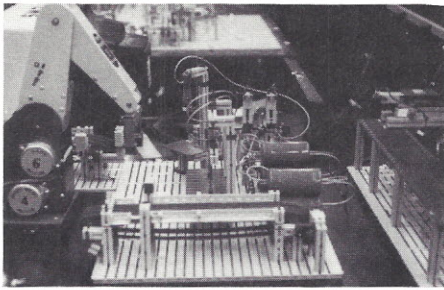


Photo 2. Functional models can extend the instructional potential of tabletop equipment. The University of Central Florida Industrial Engineering Department work-cell model shown here incorporates both fischertechnik pneumatic components and a Micro-bot™ robot arm.

machinery is expensive, requires quite a bit of space, and also has some safety considerations associated with it. It turns out that scale-modeling is a very effective way of providing laboratory experiences. You can teach all the principles of computer control and interfacing, process operations, process modeling, operator training, and the whole range of computer-aided manufacturing functions. We've been doing it going on three years now and have been very happy with the flexibility that we can get out of it."

At a lower level of schooling, eleventh- and twelfth-grade students in Robert Younker's electronics classes at Southfield High School in Southfield, Michigan, have simulated an automated assembly operation. Along with high-tech sensors, robots, and 25 pages of computer program, the simulation includes a hybrid gravity-feed

delivery system improvised out of fischertechnik parts, a tin can, and a piece of wood (Photo 3).

Younker characterizes the learning process for the student model-builders as one of continual evolution. The model, he says, has been "drawn and redrawn, built and rebuilt, torn apart, modified, and improved upon—considerably. One problem was that [the students] kept coming up with a better idea. They said, 'No, we don't like it the way it is. Let's tear it apart and make it a little better.'"

Another "problem" has been typified by the intense involvement of Scott Berman, the student who acted as chief engineer on the project. Younker relates, "You can't tear him away from the model. All of a sudden I look up, and it's the next hour, and he's still sitting back there. I get calls from other teachers saying 'Hey, he's got to come to our classes too.' So I try to watch for that and kick him out. Some of the other students are the same way. They really get involved in it and they don't even notice the passage of time."

Children can start learning from fischertechnik construction sets at an early age. The only prerequisites are an interest in how things work and the eye-hand coordination and fine-motor control needed to interconnect the tiny components. No tools are required for construction.

After an initial "messing-around" period, youngsters who are able to understand nonverbal instructions can be encouraged

to construct simple mechanisms and investigate levers, linkages, pulleys, gears, cams, ratchets, brakes, clutches, sliders, and lead screws.

Model-construction sets seldom include static, mechanical, electromechanical, and electronic components in the same system. Fischertechnik kits are an exception. Even pneumatic components are integrated into the system. (The pneumatics kit includes cylinders, actuators, throttles, valves, cams, air lines, and numerous accessories.)

A skillful teacher can introduce ever more complex concepts and principles as his/her students progress to more advanced work—through whatever series of hands-on projects intrigues them. Projects can be drawn from a variety of technological arenas—even entertainment. A pair of junior-high-aged girls at a computer camp recently constructed a microcomputer-controlled carnival ride from fischertechnik parts.

Tabletop Technology can be used at all levels of advanced study. Not only is it being adopted in undergraduate and graduate engineering programs and teacher-training programs in industrial education; it is also finding its way into continuing-education seminars and industrial R&D labs.

At Northrop University in Los Angeles, David Aldrich is coordinator of the Automated Manufacturing Systems program in the Department of Engineering Technology. In the lab that he has set up, industrial engineers and students work together on robotics projects such as welding, deburring, adhesive laying, and spray painting. In a graduate-level course entitled Automated Manufacturing Systems and Robotics, students are organized into systems teams to design, build, test, and run tabletop factories (Photo 4).

Speaking of the applications of Tabletop Technology in continuing education, Aldrich points out that, "there are a lot of practicing engineers who did not get their schooling during the Information Age. They have not learned robotics or computers. And some of those engineers are now responsible for implementing such devices in factories.

"By bringing [the engineers] into a small-class situation of six to ten students at the graduate level, we can take these students and put them through an entire course as far as the startup, feasibility studies, manufacturing, design evaluations, and

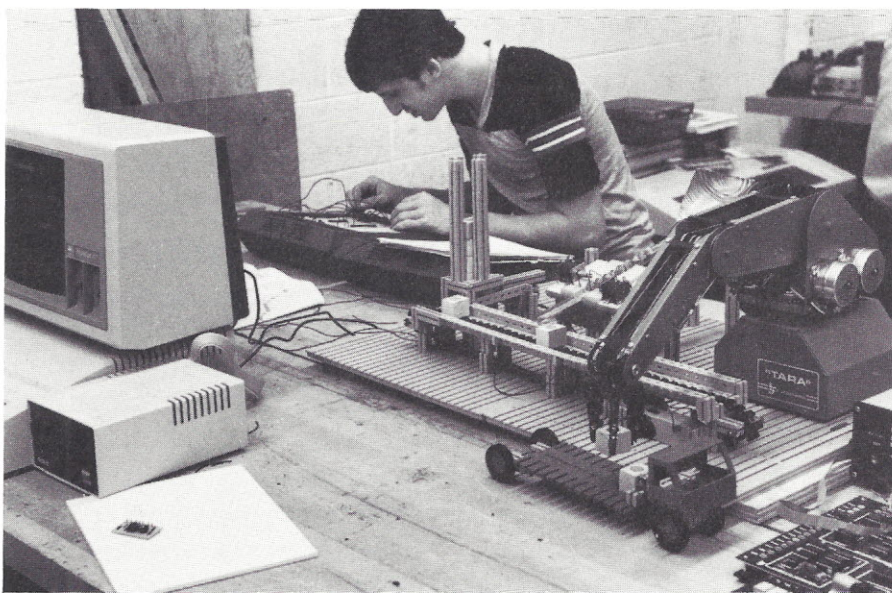


Photo 3. Students at Southfield High School have used fischertechnik parts to simulate an automated assembly operation. Here student Scott Berman makes circuitry modifications on the Heath training systems. The model is controlled through the Apple II and the Heath trainers.

system construction. They can also explore the computer-interface problems as well as

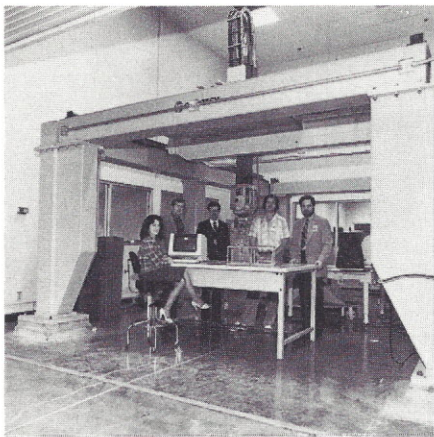


Photo 4. Dwarfed by its real-life counterpart, a fully functioning model of the three-axis gantry of a Cybotech G-80 robot serves as a design tool as well as an instructional device for staff and students at Northrop Corp. and Northrop University. Meeting within the Cybotech gantry are Barbara Serrano, student; David P. Aldrich, Northrop University Coordinator of Automated Manufacturing Systems; Terence F. Hall, Technical Manager, Northrop Corp. Automated Composite Center; Ken A. Marrs, student; and Steven P. Zonis, graduate student.

interface problems with different systems within the modeled configuration—putting robot A with robot B, or determining the time-cycle variances with automatic guided vehicles, for example. All these can be modeled with fischertechnik.”

The affordability of Tabletop Technology modeling is another important consideration. As Aldrich affirms, “The number-one problem in colleges now is cost. A full-scale working system would run into the hundreds of thousands of dollars. We’re talking about conveyors, robots, numerically-controlled machines, and different material-handling devices. Where we run into a problem also is that such high-cost equipment is not flexible. We can’t move it around. We can’t change it once we bring it into the university.

“Tabletop Technology models simulate exactly what the larger systems do, but on a smaller scale. You can change the model. Once you’ve made the initial model, you can reconfigure it.”

Aldrich has worked closely with Terence Hall, technical manager of Northrop Cor-

poration’s Automated Composite Center. Hall is not only convinced of the value of Tabletop modeling in research and development, he is also pleased with its power to communicate persuasively.

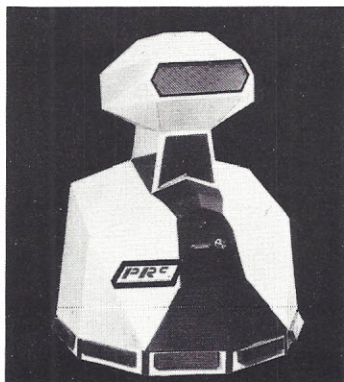
As he puts it, “I believe that it is easier to sell an idea to top management if you can show them exactly what it is you want, especially if they are involved and get to push a button themselves and make the model move. If a picture is worth a thousand words, then a working model is worth a library.”

James Durkin and Francine Foster, founders of Creative Learning Systems, Inc. and originators of the TransTech Systems, have designed and developed numerous instructional programs, equipment packages, and facilities.

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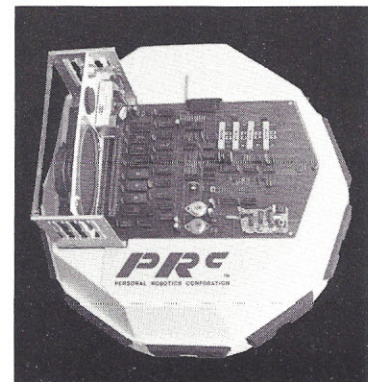


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ROBOTS IN THE CLASSROOM

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Robots are captivating the imagination of the American public. Practically every magazine I have picked up in the past two months has some reference to robots. These references are not to industrial robots, but to personal robots. The public is carving a niche in its collective heart for cute little creatures that move, talk, and can perform a few other simple life-like feats. All but the most forward-thinking are still reluctant to purchase their own personal robots, but no one will turn down the opportunity to observe someone else's neat little friend.

For those of us involved with the personal robotics industry, this fascination produces a great deal of publicity, but does not necessarily help meet the costs of production and continued research and development. Current personal robotics technology needs an identifiable, existing market besides the hobbyist and the early adopter. Such a market exists. It is the education market.

Public school personnel are aware that, as a whole, they have been painfully slow to integrate microcomputers into the classroom. They appear to want not to make the same mistake with small, mobile robots. School districts are ready to buy when someone can show them how to integrate robots into the existing curriculum and can demonstrate the results in terms of student motivation, learning and retention.

Integrating personal robots into the curriculum does *not* mean adding courses in robotics technology. Integration means using the robot as a teaching tool in reading, language, math, science, and other traditional subject areas. As a result, students are learning about the subject areas, they

are learning about computers and personal robots, and they are learning how to fit these new technologies into their lives. The schools do not have to find more room in an already full daily schedule for more courses, or run the risk of shorting one area of learning to make room for another. Integration becomes a natural process.

These ideas are not just theory. They are based on actual experience. I have been developing and pilot-testing educational material for the RB Robot Corporation in Golden, Colorado to be used with the RB5X robot. The materials are designed to help young people and adults learn to effectively create their own programs for the RB5X using RB Robot's Robot Control Language with Savvy. All of the ac-

tivities are designed to enhance the user's problem-solving abilities. The activities are arranged in order of difficulty and address each of RB5X's specific capabilities.

Once the activities' design and content were determined, a pilot test site was needed. The Las Cruces, New Mexico Public Schools' elementary summer school program was secured for this purpose. Las Cruces is primarily a rural agricultural community located in the southern part of the state, about 50 miles north of El Paso, Texas and the Mexican border. The town of Las Cruces has a population of 56,000 and is neither a center of affluence nor high technology. Many families do not speak English at home. The school district has only recently received sufficient fund-



Photo 1. Students can use robots in the classroom to learn about mathematics, the sciences, and also how their language works. Here students are programming the RB5X to speak a series of phrases. (Photo by W. J. Morrissey.)

ing to place computers in the elementary schools.

The summer school program's primary aim was remediation in language, reading, and mathematics. The students ranged in age from seven through 13 and were from varied ethnic backgrounds and economic levels.

Pilot test participation was voluntary on the part of all ten mathematics and oral language teachers. All of the teachers whose students were eligible to participate in the pilot testing volunteered enthusiastically. Each class had between 12 and 18 students and each class period was 55 minutes long. Most students had no previous computer-related experience although a few had computers at home. Five activity areas were divided between the ten classes. The simplest activities were assigned to the youngest students and the more complex given to the older students. A schedule was arranged to give each class three hours of hands-on time over the course of a month. No group met more often than once a week.

I was given my own classroom where I set up my Apple IIe and the RB5X. Each group of students had a problem presented to them that involved getting the robot to do a particular thing, such as move in a specified way, use the sensing devices to accomplish a certain task, speak, etc. The Robot Control Language commands needed to solve each of these problems was written on the chalkboard. Students worked in groups of three or four to devise solutions. After each group arrived at a solution, two or three students were selected as joint typists, or *robot secretaries* as one group named them. The groups pooled their solutions and decided on a single strategy. The typists entered the commands in the order suggested by the remaining students. The program was then downloaded into the robot and the robot's performance was evaluated. If students were satisfied that the robot was performing as expected, they enlarged the robot's task. If they were not satisfied, they modified the program and tried again. As the students mastered one activity they

moved on to the next level of difficulty. In some cases, difficulties delayed final solutions for several weeks.

The results of the pilot test were fantastic. I was somewhat concerned about having students with no computer background start midway in the series of activities, but my qualms were proven groundless after the first session. At the end of the first hour spent with each class, the students had developed successful programs to have the robot perform the specified tasks, but that was the least of the outcomes. Students gained many insights in mathematics that were previously unknown to them: geometric shapes and spatial relationships, the meaning of degrees in a circle, and the meaning of decimal points. All of the groups were faced with learning several computer programming techniques. They had no difficulty understanding what loops were and where and when to use them, the nature of conditional statements and how these work, the order of program execution, and the idea of a compiler.

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Students had no trouble learning to read the adult-level programming language. It was gratifying to watch a third-grade girl who obviously was not confident of her reading ability read and understand: "EXIT IF SONAR distance value is less than 100." After that first experience, the young lady constantly volunteered to read the screen (as did all of the other students). One of the most amazing outcomes to me was to see and hear non-native-English-speaking students correcting their own heavily accented speech as they perfected the speech they programmed into the robot.

Another noteworthy outcome of the pilot test was the students' retention level for new concepts learned, whether these were directly related to the material presented or the result of independent inquiry. The students in each class shared a real spirit of adventure and camaraderie throughout the entire pilot test period. All students were helpful and supportive of each other. The students are now anxiously awaiting the appearance of the robot they helped

program to participate in the coming city-wide Break Dance contest.

Why can a robot be such a special tool in education? There is, of course, the newness of the technology for students, but there are other more important aspects. The robot is a concrete, three-dimensional object that children can interact with and observe. Students can instantly evaluate the results of their work when they program a robot and know that it is easy to correct programming errors and attain the desired level of satisfaction. In other words, they learn that false starts and momentary failures are not the end of the road. Most important, students gain a feeling of control over a tangible object in their environment. This can help children to build success-oriented learning strategies and work patterns. Finally, even if robots have certain limitations that are still waiting technological advances to remove, children will readily engage their imaginations and pretend that "their robots" have overcome these obstacles and are really outstanding creatures.

At this time, the personal robot's potential as a teaching tool in the general educational process is virtually unrecognized. It is already becoming clear that the advent of the personal robot allows us to teach some things better in schools than has previously been the case; it allows us to teach other things that have been almost impossible. Educators don't know about robots yet. It is up to the manufacturers to provide the leadership in introducing the personal robot to the largest single market in the United States.

Niki Delgado is the General Manager of Rio Grande Robotics. She is a former educator with a background in early childhood education, special education, bilingual education, and educational psychology.

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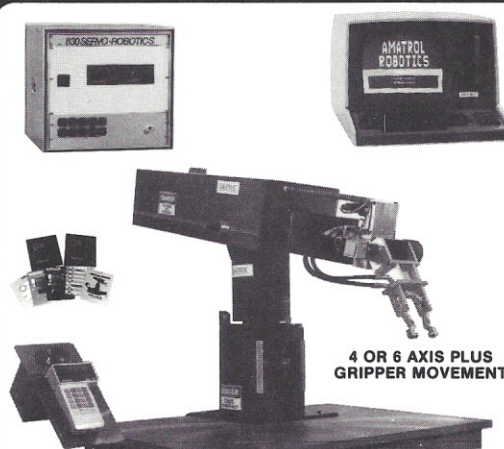
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ROBOTICS IN ELEMENTARY EDUCATION

Garrett W. Larson
Dr. Al Haugerud
Microbotics Development Corp.
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The age of quality educational robotics has been ushered in by the incredible advancements and widespread use of microcomputers in our society. Robotics is a fast growing industry and will continue to grow as more applications and functions for robots develop both for industry and home markets. The question that now arises is how to train students properly on basic robotics principles and how the robotics curriculum will best fit in the classroom setting.

Breaking robotics into its basic components and principles allows the students to grasp the use of the robot as a tool or extension of the microcomputer. One author was field-testing a robotics curriculum and system with a group of 10-year-old students. The system was designed using modular robotics units, a claw, sensors, and a Commodore 64 microcomputer. The students' assignment was to write a program that moved a two-wheeled vehicle across the floor and printed STOP on the screen when the robot hit the wall. Ten

minutes passed as they added, constructed, and pieced together a monstrous robot.

One boy, with modular robot parts in one hand and a sensor in the other, yelled, "It won't go forward. Give me another motor." Fifteen minutes were left to complete the task. As the last seconds ticked off the clock, the students pressed G for go on the computer, and the robot churned into action, heading straight for the wall. As it hit the wall, the screen flashed, "I hit a tuna," and the classroom exploded with laughter.

The robot eventually became a tool for performing many functions through the microcomputer. The more robots become tools that the students can work with and control, the more students will understand the relationships among the robot, software, and themselves.

Educational robotics devices at an elementary level should be simple to use and easy to manipulate. The more they can be broken down into their simplest parts, the more understanding students will have on the essential components of a practical robotics system.

Robotics must be taught beginning at its simplest form, input and output. Using sensors, such as a mechanical sensor, the computer can be set up to judge when a sensor is either on or off. The computer can turn on lights, motors, or whistles in repetition to demonstrate the computer's

ability to control the peripheral devices.

Students can create robotics programs by controlling more motors, enabling a robot to go forward, backward, left, and right. By operating separate motors, a fluid motion can be created.

After experimenting with motion control and continuity and grasping an understanding of programming the robot, the students are faced with unlimited options. They are free to use sensor input in coordination with motor movement and claw manipulation in order to create, develop, experiment, and execute thousands of programs. Only programming skill and imagination limit the use of this information in more complex interactions.

Using the accuracy, speed, and analytical capability of the computer, robots can be an excellent way to teach and experiment with math, science, and other learning activities. The robot also becomes an avenue to teach geometry, with its ability to draw shapes and patterns using a felt pen. The robot can help teach calibration and distance as the students make the robot go ten inches, turn left 90 degrees, and continue ten more inches before stopping. The entire concept of using the computer to perform practical functions with electromechanical devices is vividly taught, and the kids can have fun learning.

To work with educational robots, one must understand the interaction of simple

Garrett W. Larson is president of Microbotics Development Corp., a high-tech educational robotics system manufacturer in Bellevue, Washington. Dr. Al Haugerud is a professor of science education at Seattle Pacific University in Seattle, Washington. He has spent two years field-testing and developing robotics concepts and an elementary robotics curriculum in various primary and secondary schools in the Pacific Northwest.

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sensory inputs, such as mechanical (touch), light, and magnetic inputs. This is the basis for understanding the relationships of both robots and humans in our environment and how they interact with it. Children can use a simple sensor input to turn a circuit on or off, thus reaching beyond computer input by actually feeding simple information to the computer about its environment.

From this they learn how to use software to process the information gathered by the sensors on the robot. They use this information in programs that interact through the software to the environment. An example is having students build a robot that moves about the room in search of the light beam from a flashlight on the floor. After finding it, the robot should stop and print "I found the light."

The simple robot, as an extension of the software programmed by the students, can effectively teach the logical reasoning inherent in programming. A tangible understanding of how the computer can be used as a tool for various applications is taught as the students work with and manipulate the robot to perform tasks. They constantly refine their activities to perfect their programs, and use the robot as an outlet to actually work with their programs beside them. This way, the action of the robot provides obvious evidence of the effectiveness of the program and can be judged on the robot's performance.

A major component of a robotics system is to assimilate its relationship with industrial and functional uses. An example would be a simple gripping mechanism or claw. With this extension, the robot can be programmed to perform simple grabbing and lifting functions, using the computer software as an internal "thought" procedure and the robot as an extension of the computer in the real world.

As robotic systems become more readily available for the classroom setting, it becomes obvious that software is the focal point or the "brain" of the robot. The software is used to read sensor input and digest and process it in a logical manner. The software becomes the thinking tool for the students and their robots. It puts no limitations on the applications and interaction that a student can have with the computer and robot. The software encompasses the robot and its environment, letting the students expand their perceptions of a computer by working with the fundamental element of robots, the software

driving the machine.

By default, BASIC has become the programming language of elementary and secondary students. They learn the language not only in a school setting, but outside of school as well. An understanding of BASIC will benefit any child because of the applications of computers outside classroom teaching and because of BASIC's simple and concise command sequences. In the classroom, Logo can be used to create fundamental geometric designs with a robot and pen. With both languages, computers help motivate students to work with and use the computer as a tool. As children refine their skills and perceptions of computers and their capabilities, they gain a broader grasp of how their relationships with robots will create a very powerful partnership in the future.

As students become aware of the current applications and future potential of robots, robots undoubtedly will become more function-oriented. They eventually will be built to perform many functions attributed to humans and will be specifically designed to best serve as extensions of the computer. Educational robotics systems will become a tool for teaching computer literacy.

Robotics will play a large role in artificial intelligence. With the simple interaction and functions of a robotics system, students will gain greater knowledge of the potential of robots and computers and create software with more logical and comprehensive structure. The robotics system will help unlock limited input and output and open new channels of communication for the software and computer.

During this time of experimentation and forming, simple concepts must be stressed to create a quality educational basis of robotics principles. These concepts will lead to new ideas and products, new ways of dealing with problems and information. The elementary level is the place to begin teaching robotics and its relationship with computers. Robot, computer, students, and teacher can work together to better understand new technology and its future.

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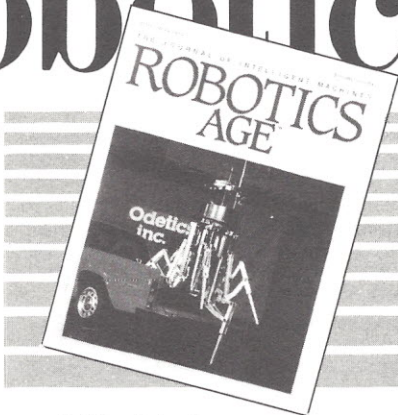
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REMCON TEACH ROBOT

by Raymond GA Cote

I recently received a call from Geoff Chapman, who represents a British company, Remcon Electronics, Ltd., and was visiting the United States. We managed to get together for an hour or two at the Boston airport, where Geoff proudly displayed a wonderful little educational robot arm being distributed by Remcon. The machine is designed as a serious teaching aid for schools, colleges, universities, and interested experimentalists.

The first thing that struck me about the robot was its compact size. Geoff carried it, with demonstration control box and batteries, in a standard briefcase. It was also very light, weighing only 2.5 kg including the base plate, since it was made from plastic molded parts.

The robot, dubbed Teach Robot (TR2), is an injection molded plastic arm, driven by lead screws which are mounted on the various arm segments. Since the motive force is mounted separately for each arm segment, the interplay between arm segments is reduced to a minimum.

The prime movers for each of the Teach Robot's six functions are custom-made DC motors with shaft encoding and thumb wheel neatly incorporated at the brush end of the motor. Each motor has an optical encoder which provides position information. Four of the motors drive lead screws for controlling the basic arm movement. One lead screw, secured to the mounting base, rotates the entire robot arm through a 90° turn. Each of the major arm segments are also controllable through a 90° reach. Although at first this appears to be limiting, still it provides sufficient flexibility for most actions. The gripper position and jaw motion are controlled via two brass worm gears and a nylon worm wheel. The jaws move through a 180° arc and the wrist can roll 540°. The only limit on wrist roll is the cabling attached to the jaw motors. All these motors and lead screws combine to produce a rated 0.5 mm positioning repeatability.

The Teach Robot is packaged in a compart-

mented polystyrene box as a number of ready-built wired and tested subassemblies. The assembly task takes about six hours, although

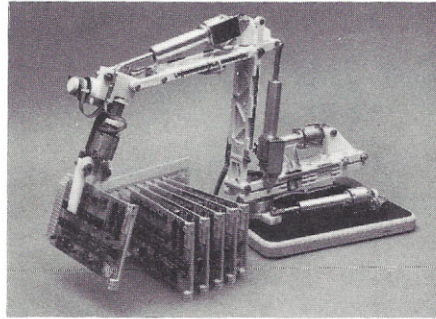


Photo 1. Overview of the Teach Robot. The TR2 is mounted on a demonstration base which supports the machine and provides an anchor for the base-pivot lead screw. The Eurocard controller cards each monitor and control an individual axis. All of the arm elements are injection molded parts. The lead screws and housings are metal. Metal bushings are used at each joint to reduce wear and friction.

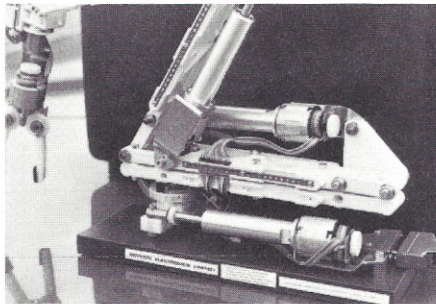


Photo 2. A lead screw and accompanying drive motor control each axis. The base-rotating lead screw is secured to the base. Also shown in this photo is the DB-25 connector at the right of the board, used to interface with the Action Box or a control computer.

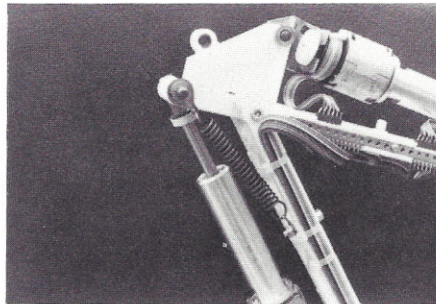


Photo 4. Each drive motor has a thumbscrew mounted on the back. Although it is rather time-consuming, it is possible to physically control the arm position by using these thumbscrews. Since the thumbscrew is mounted directly to the motor shaft and the feedback encoders, feedback is provided to a control computer when the axes are manually moved. This is particularly useful when teaching the robot the finer points about a motion.

veteran kit builders can construct it faster. Actuator wiring is via a five-way ribbon cable, terminated locally to a factory-fitted six-pin plug.

The components (of engineering plastic) have metal bushing inserts molded into the joints. The moldings carry prethreaded brass strips along their length, on which experimentalists may affix their own features. The wiring harness is supported by retainers incorporated into the structural moldings.

ROBOT CONTROL

In its simplest form, the Teach Robot can be driven by an attached Action Box. The switches on the box allow the experimentalist to connect a DC power source 12 to 20 V at 1.5 A to drive the individual motors. The motors are dynamically braked by shorting the motor when the switch is released.

The next level of control is provided by a set of computer controller cards. The controller consists of six Eurocard-compatible cards which connect the robot with any computer. Each board drives one Teach Robot function and carries circuitry to provide two adjustable speeds of operation—fast and creep. The card also maintains a counter to track the actuator position and state.

The system motherboard can accept up to nine boards, providing the option for further expansion and use with stop switches, other encoders, etc.

Perhaps the most amazing part of the entire robot system is its price. The quoted U.S. price for the arm itself, including a 90-page manual giving full mechanical and electronic details, is \$377.50. The Action Box is priced at \$61.50 and the complete control computer is priced at \$275.

The Teach Robot will be available in the United States starting in September. Distribution will be handled by Remcon Electronics, Ltd., PO Box 148258, Nashville, TN 37214, telephone (615) 361-3936.

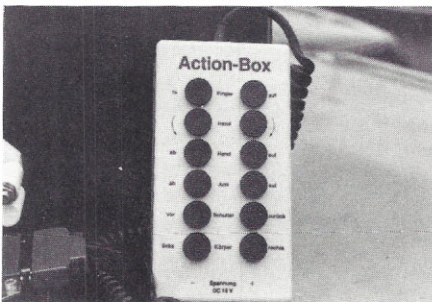


Photo 3. The Action Box, here shown in the German edition, is a simple control box for demonstrating the arm. The buttons simply provide a voltage to the motors and short out the windings to lock them into place when the buttons are released.

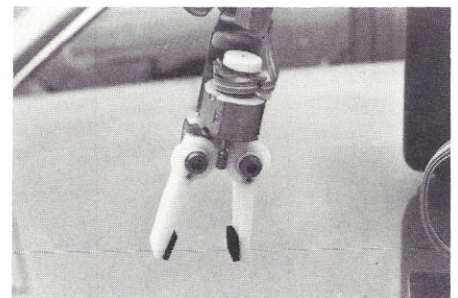


Photo 5. This close-up of the gripper shows the brass worm and nylon gear arrangement. One of the Teach Robot's few failings is the absence of a parallel-jaw gripper. This jaw arrangement does provide sufficient force to pick up an object the size of a pen. However, it would be more useful if it had parallel jaws.

MORAVEC'S MOBILE ROBOTS

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THE STANFORD CART

Hans P. Moravec, a researcher at Carnegie-Mellon University's Robotics Institute, understands better than most people that progress takes time. He knows that even when your goal is clear, the path to reach it may not be. You may have obstacles to overcome or avoid. But to avoid them, you must first recognize them. Occasionally, you may perceive an obstacle that is not there, or you may find an obstacle as you near your goal that you did not see when you first set out.

Clearly, making progress can be a slow process. You scan the terrain and interpret what you see. You plan a path toward your goal, and you take a step in what your analysis indicates is the best direction. After you take that step, you look around again and refine your perceptions and your plans. Then you take another step and repeat the process until you reach your goal.

Moravec's research reflects that philosophy. His present work at CMU, developing mobile robots with sophisticated vision capabilities, is the natural extension of work he did as a student at Stanford University's Artificial Intelligence Laboratory (SAIL). Surprisingly, his goal is not robot mobility. Rather, he sees robot mobility as a step toward a much more ambitious goal. "I see mobile robots as one of the surest ways of getting at general artificial intelligence," he asserts. To some people, that statement is surprising, but Moravec makes a most convincing case.

Moravec's mobile robot research exemplifies the philosophy of step-by-step progression. His mobile robots have a goal, identify obstacles, and plan their path around those obstacles to that goal. They may take a long time getting there, but they diligently plan and move toward their goals, meter-by-meter.

Moravec's Ph.D. work was an exercise in patience. From 1973 through 1980, he labored over what he described in a SAIL technical report as a "pre-existing vehicle with fairly crude mechanical and electronic attributes" to produce a "rickety camera-equipped rover" called The Stanford Cart, which was controlled over a radio link by "a computer system of medium capability."

His cart's ultimate achievement consisted of navigating across an obstacle-strewn field, reaching a goal approximately 20 meters away in approximately five hours. Although by human standards that performance is hardly noteworthy, the Stanford Cart deservedly received considerable attention in the AI community.

Today, at CMU, Moravec leads a research activity building new rovers (Pluto, Neptune, and Uranus) which have many significant advances over the Stanford Cart. But to fully appreciate the CMU Rovers, we must first understand their venerable predecessor.

Photo 1 shows the Stanford Cart, a 1 meter square by 1.5 meters high four-wheeled vehicle. Its television camera transmitted a black-and-white picture 280 pixels wide by 240 pixels high, having four bits (16 levels) of gray scale. An onboard controller received remote control information over citizen's band radio. The camera moved along a 52 cm. horizontal track, producing images of the same scene from multiple vantage points. In actual operation, the camera took nine pictures at precise 6.5 cm. intervals, producing a nine-eyed composite view of the world.

Before an actual obstacle course run began, a rectangular array of dots with a single cross was used to calibrate the vision system. Photo 2 shows a view of an

indoor obstacle course and the calibration pattern. Calibration determined both the camera's focal length and distortion, which the computer then used to correct images during the run.

After calibration, the cart was taken to its obstacle course, given a goal relative to its position and heading, and instructed to begin. The camera took nine pictures and transmitted them to the computer. The computer first enhanced the pictures, a step necessary because of "snow" in the video link. Then it analyzed the video data, locating features by comparing the pictures to each other and to features previously identified. Finally, it determined a path

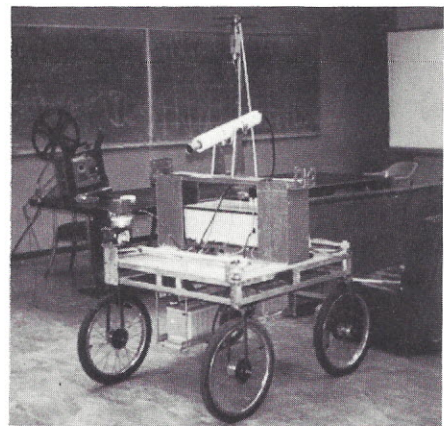


Photo 1. The rickety Stanford Cart, Moravec's first mobile robot. (Photograph courtesy Hans Moravec. Photographer: Rodney Brooks.)

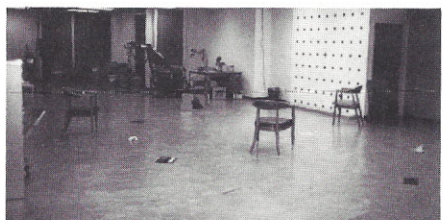


Photo 2. An indoor obstacle course for the Stanford Cart. Its camera calibration pattern is on the right hand wall. (Photograph courtesy Hans Moravec. Photographer: Rodney Brooks.)

which enabled it to reach its goal. Based on that path, the computer sent a signal to activate the steering and drive mechanisms, and the cart lurched about a meter along the path.

The entire "thinking" process took 10 to 15 minutes, depending on the complexity of the situation and the load on the computer. Part of the reason for that length of time was the cart's unpredictability. Because it had no wheel position sensors or range finders, and because the action of its drive and steering motors was not easily modelled, its movement was predictable, under ideal conditions, to no better than 20 percent accuracy; it simply was not very repeatable. Furthermore, external conditions, such as the slope and texture of the ground and the battery voltage, also influenced cart motion.

A partial solution to this uncertainty was to use the computer not only to analyze the several images, but to compute the cart motion during each interval based on the features identified in those images. This solution was far from ideal. In one noteworthy case, errors in successive computations accumulated and the net error became so large that certain features were determined to be in more than one place.

VISION AND PATH PLANNING

The vision analysis system used on the Stanford Cart was based on the concept of *features*, points which could be unambiguously located in different views of a scene. Features were identified by their contrast with other pixels in their immediate vicinity, using an identifier subroutine known as the *interest operator*. Corners were excellent features since they have high contrast in orthogonal directions. Uniformly colored regions and simple edges were not deemed interesting. Intersecting edges were very interesting. Photo 3 shows the interest operator at work in two different scenes.

The interest operator occasionally identified spurious features. For example, if a distant object was partially obscured by a nearer one, there was an apparent corner. Such features, however, were eliminated by a *correlator* subroutine.

The correlator used a successive refinement method to match features identified in any two pictures. It operated by representing each feature as a series of images, each covering a smaller portion of the view-

ing area, and each represented as a 6 by 6 array of values. Each value was an average of a set of pixels. At the coarsest scale, the correlator examined a 15 by 16 array of possibilities to determine the portion of one picture that had the best correlation to each feature in the other picture. Then it proceeded to the next finer scale.

The stereoscopic vision computation used the correlator to match features found in the central picture to each of the other eight images. Since the terrain on which the cart moved was fairly level, the program could restrict its feature-matching search to a relatively narrow horizontal band for each feature.

Even with the restricted search range, the correlator sometimes matched features incorrectly, but the effect of incorrect matches was diminished by using the data from all nine images. Each of the 36 possible pairings of the nine correlated features was used as a stereoscopic baseline to compute a distance to the presumed actual feature. If all eight correlations were correct, all 36 distance calculations would agree to within a small margin of error. In practice, at least a few correlations were likely to be incorrect, requiring a statistical interpretation of the data.

Using that statistical interpretation, Moravec found that the Cart could distinguish between real features and spurious ones if as few as two or three of the eight correlations were correct. The data based on real features produced a statistical con-

sensus as to the distance from the cart to the feature. Spurious features appeared to be at many distances at once.

Figure 1 shows how the cart, having identified features in its field of view, planned its path to its destination. If a feature was above the maximum height of the cart or flat on the floor, it was not considered an obstacle. Other features, represented in the computer as *fuzzy ellipsoids* due to the uncertainty in their measured position, were approximated by circles which are roughly their shadows on the floor from an imaginary beam of vertical light shining from above. The radius of each circle was increased by an amount large enough to take into account the physical dimensions of the cart and its uncertain control.

To take into account the cart's steering limitations, the program added fictitious obstacles to eliminate the choice of an impossible first step. Then the program used a standard minimum path-length algorithm to select its path, and directed the cart to take a step. Each step was roughly an S-shaped curve, designed to position the cart properly for its projected next step.

At the end of each step, the computer had to recompute the Cart's three-dimensional position, allowing for some vertical motion. Once again, Moravec called on the correlator for help. The program correlated features in the central image at the Cart's new position with features seen at its last position. As before, not all

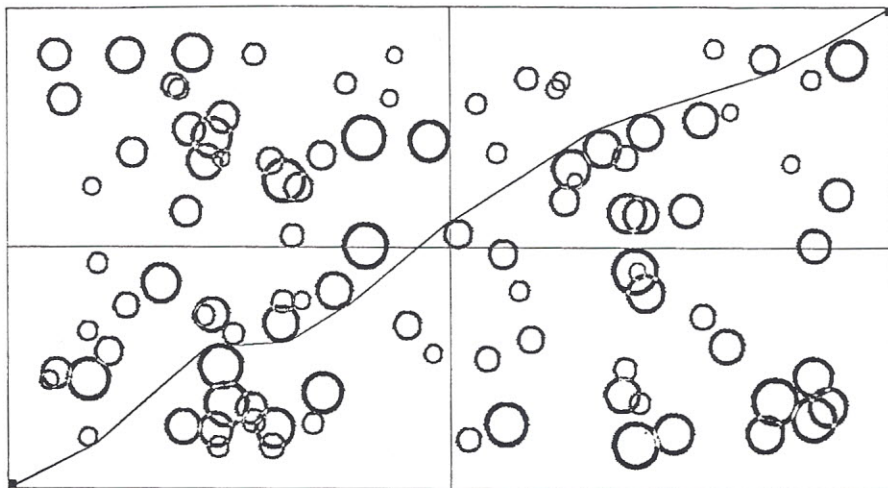


Figure 1. A planned path through a field randomly strewn with obstacles. The radius of each obstacle has been increased to account for the Stanford Cart's size. (Based on a figure from "Visual Mapping by a Robot Rover" by Hans Moravec, Stanford Artificial Intelligence Laboratory, April, 1979.)

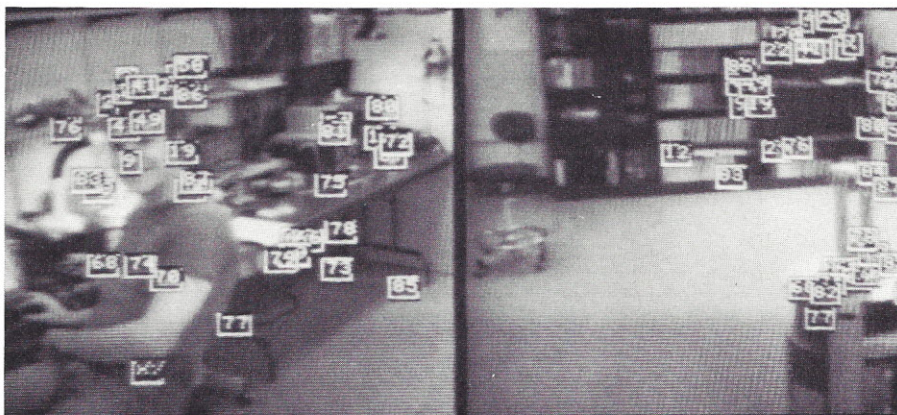


Photo 3. The interest operator in action on two scenes from the Carnegie-Mellon University Robotics Institute. These television images, produced by CMU Rover Neptune's cameras, use much the same interest algorithms as the Stanford Cart. Neptune is apparently interested in a person in the scene on the left and its older sibling, Pluto, in the scene on the right. (Photographs courtesy The Robotics Institute, Carnegie-Mellon University.)

features were real, and the correlations were not perfect. But pairs of real, stationary features have unchanging separations, a fact used by the Cart's program to identify features it could trust. If the trustworthy features were new, the program added them to the features already in its world model. It then computed the best approximation to the motion and rotation of the cart during the last move, based on

the changes in apparent position of all the correctly correlated features.

Unfortunately, this type of calculation is subject to error, and the errors on successive steps may accumulate to the point that features, previously stored in the cart's world model, appear again as new features beyond the range of uncertainty of their previous incarnations. This actually happened in one memorable test run. The

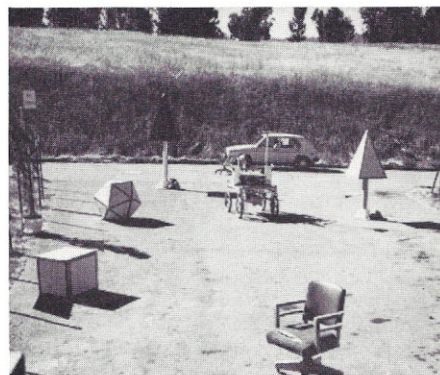


Photo 4. The Stanford Cart enjoying a stroll in the California sun. (Photograph courtesy Hans Moravec. Photographer: Rodney Brooks.)

Cart thought that its path was blocked when in reality there was nothing in its way. The poor Cart was literally seeing double. Its planned path, says Moravec, was "silly."

Moravec had no choice but to clear out the world model and hope that the Cart would be able to spot the obstacles again. Unfortunately, it failed to notice a large cardboard icosahedron four meters ahead of it. The cardboard was too uniform in appearance and the background shifted too rapidly at close range for successful identification. The cart collided with the

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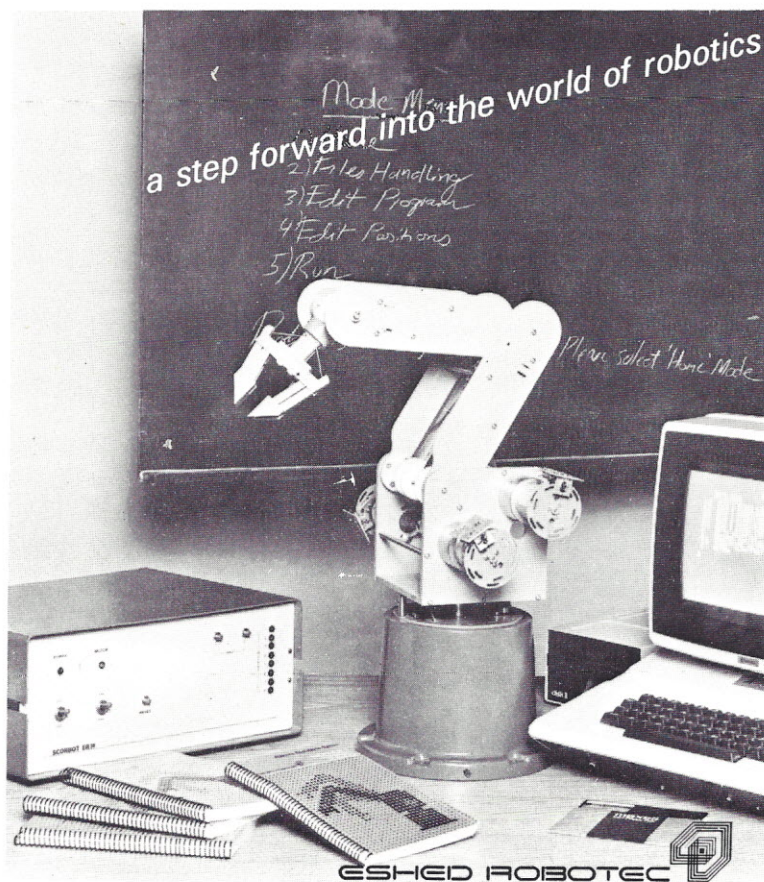
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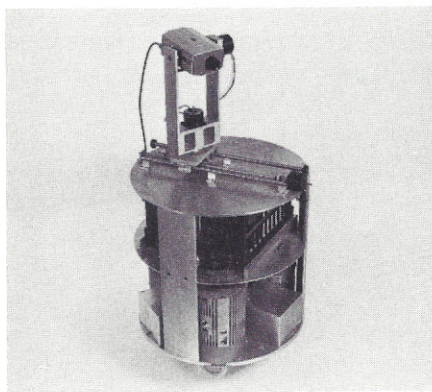


Photo 5. Pluto, the first CMU Rover. Pluto, like the Stanford Cart, has a multiview vision system. Three pairs of independently controlled wheels give it a large range of translational and rotational motion. (Photograph courtesy The Robotics Institute, Carnegie-Mellon University. Photographer: Gregg Podnar.)

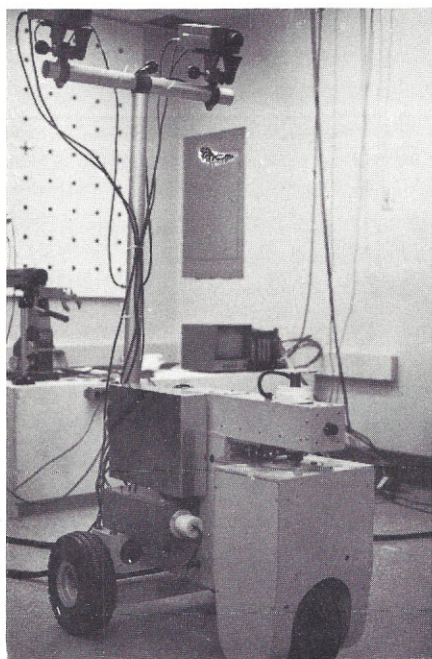


Photo 6. Neptune, the latest, but not the last CMU Rover. Neptune has binocular vision and moves like a tricycle. (Photograph courtesy The Robotics Institute, Carnegie-Mellon University.)

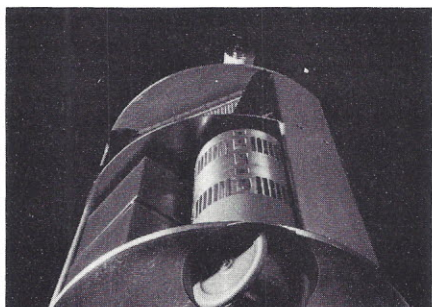


Photo 7. One of Pluto's wheel assemblies. (Photograph courtesy The Robotics Institute, Carnegie-Mellon University.)

SHAFT ENCODER

DRIVE MOTOR

SHAFT ENCODER

STEERING MOTOR

DIFFERENTIAL GEAR

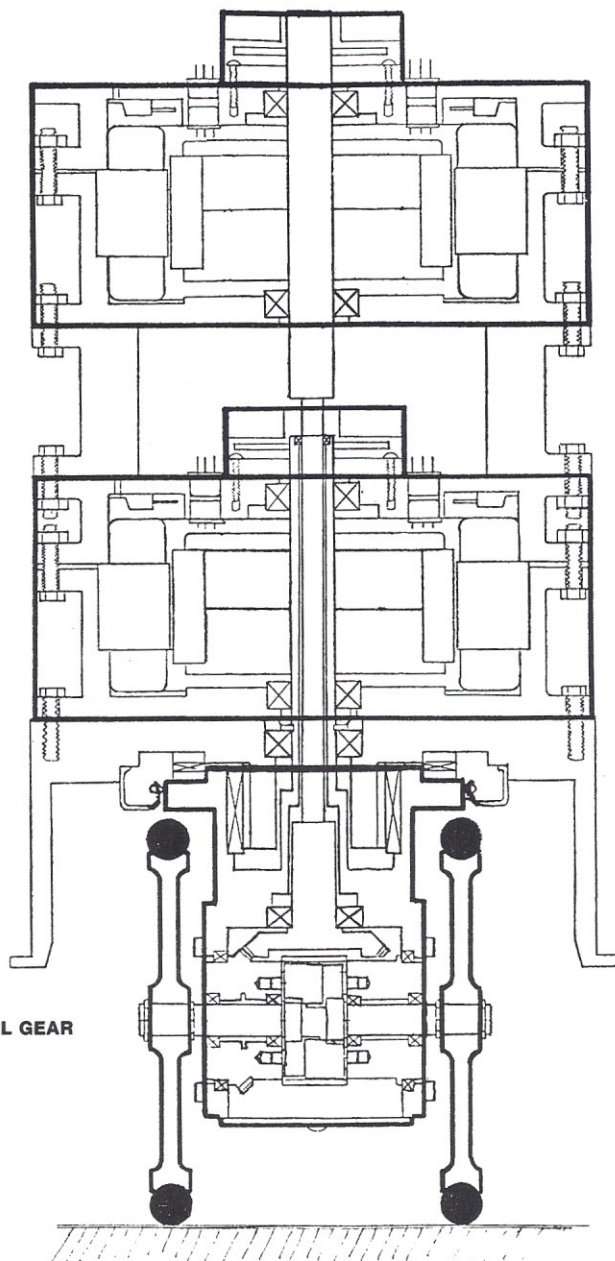


Figure 2. A drawing showing some of the detail of Pluto's wheel assemblies. (Drawing courtesy The Robotics Institute, Carnegie-Mellon University.)

icosahedron, and Moravec had to move it out of the way manually.

The Cart suffered two other amusing mishaps, one outdoors and one indoors. In the outdoor test, it identified a number of very sharp features which were simply shadows in the California sun. Since these features moved as much as half a meter while the computer was thinking, the computer's world model became confused. Photo 4 shows the cart in the midst of one such run. In the indoor test, human error set the goal to be behind a wall. When the cart got close enough to recognize features on the wall, it repeatedly backed up to try

to find a path around them, obviously without success.

CMU ROVERS

At Carnegie-Mellon University, Moravec is no longer encumbered with a pre-existing rickety vehicle or by graduate student status. He now supervises several students of his own who are involved in building and experimenting with the CMU Rovers.

The first Rover, Pluto, shown in Photo 5, has been the subject and product of extensive work. Neptune, shown in Photo 6, has binocular vision and a less complicated (but less flexible) mobility system. It was

completed in early 1984. Uranus has not yet been built.

Pluto, the most general and ambitious robot of the three, is a three-level cylindrical device about a meter in height and 55 cm. in diameter. Its improvements over the Stanford Cart are in three major areas: mechanical reliability and control, computer processing power, and sensory input. Moravec's group plans to add a manipulator arm, eventually enabling it to open a door and roll through. But, for the present, they are concentrating on questions of mobility, computational speed, and navigation.

The major mechanical advance is the system of three pairs of wheels, each wheel assembly controlled by a pair of motors. Each motor is controlled by its own microprocessor. Photo 7 and Figure 2 show a typical motor-wheel assembly. Having a pair of wheels in an assembly provides for low friction steering while the robot is stationary.

One motor controls the steering of the assembly, turning a shaft so that the wheels turn in a small circle. The other motor turns a shaft connected to a differential

gear between the two wheels. If it turns one way, the wheels roll forward; if it turns in the opposite direction, the wheels roll backward. Each shaft has a 4000 count per revolution optical shaft encoder, providing excellent resolution of each wheel's motion.

The wheel control algorithm maintains the orientation of the wheels such that lines through their axles meet at a common point. If the point is infinity, i.e. the wheels are parallel, purely translational motion results. If the point is directly beneath the center of the robot, the motion will be purely rotational. By adjusting the position of that point and the speeds of the motors, any combination of translational and rotational motion can be achieved.

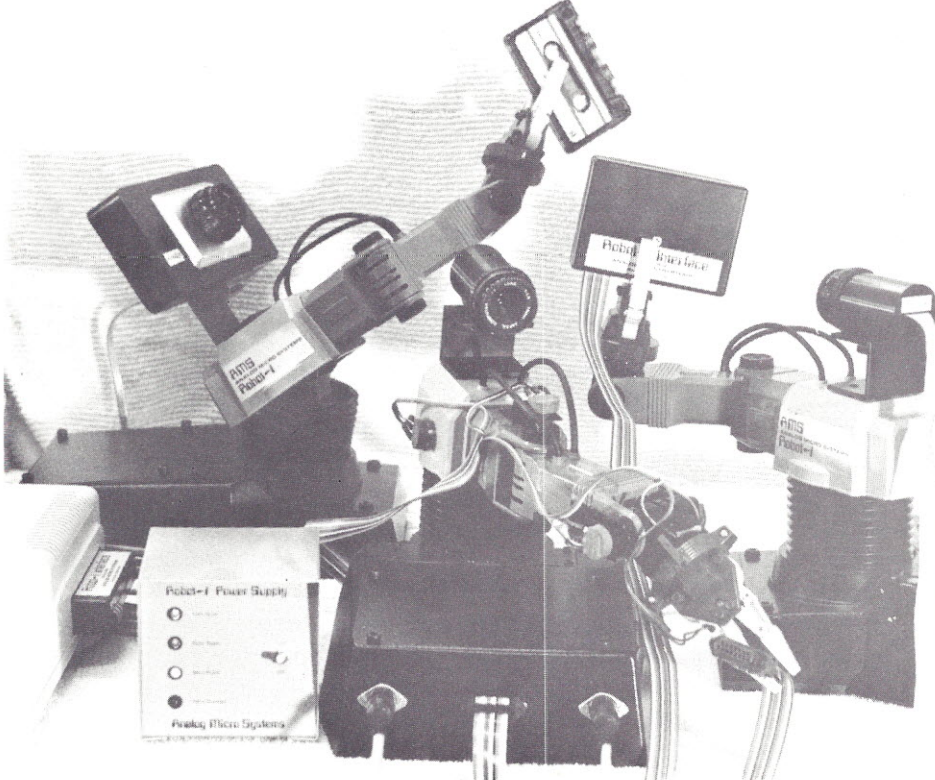
This range of capability provides an unexpected benefit: a reducing gear capability. At a given motor speed, the faster the robot spins, the slower it moves forward and the steeper the slope it can climb.

Theoretically, the motion of any pair of wheel assemblies can completely define the motion of the robot. However, wheel slippage, and to a much lesser extent digitization uncertainties, can lead to ambiguous

results. Thus, the CMU Rover studies will include visual navigation as well as navigation derived from shaft encoder information. However, the motion of the CMU Rovers will be much more reliably measurable and much more repeatable than the motion of their predecessor. Blind navigation may be possible for Pluto and friends.

On Pluto's bottom level, along with the motors, are the batteries. These provide power to run the motors, the onboard microprocessors, and other electronics, which reside in the middle level. The microprocessors were selected on the basis of computational capability and electrical power consumption. The motor-control processors, Motorola 6805s, read the shaft encoders and control the motors according to the signals provided by a processor known as the Conductor, a Motorola 68000.

The Conductor orchestrates and coordinates the motions of the individual motors to provide the desired motion. Like individual musicians, the motor-control processors provide the inputs to their instruments in response to the Conductor's guidance.



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This Conductor interprets not one, but two, scores. One score is provided by the Controller, which provides the desired position as the robot moves. The other is the Simulator which uses data from the motor shaft encoders to maintain a dead-reckoned model of the Rover's position.

Together with the motors, shaft encoders, and related sensors, the three 68000s form a classical feedback system. The Simulator and shaft position sensor hardware form an elaborate position sensing system, the Conductor and motor assemblies are the actuator, and the Controller provides the central control. The feedback takes place in the Conductor. It uses sensed information about the Rover's position to determine what signals, sent to the motors, will move the Rover along the desired path.

Pluto also has several other onboard processors, as well as the use of some very powerful computers. One onboard processor, another Motorola 68000, is dedicated to communication between the Rover and the main computer, a VAX 11/780 with a powerful ST-100 array processor and a custom high-speed digitizer. The main program interprets the visual information provided by the camera and plans the path.

The camera, being more advanced than the decade-old device on the Stanford Cart, provides a considerably better signal. Likewise, the communication link is improved. The camera broadcasts a UHF or microwave signal to a high bandwidth digitizer system whose output goes to the VAX. The Rover receives its controlling data as error-corrected and checked packets of infrared light.

Pluto's vision and path planning software are, at present, little different from their Stanford counterparts. However, the increased computational power and improved signal quality have vastly increased Rover's speed. Pluto's initial steps were separated by only 2 to 3 minutes.

The Rovers will also have other capabilities beyond those of their predecessor, including Polaroid sonar ranging devices, infrared proximity sensors, and contact switches. The sonar can provide navigational information, supplementing the visual and motor-shaft signals. The proximity sensors and contact switches provide final defenses against collision. On Pluto, two Motorola 6805s monitor those sensors and can provide, on request, that sensory information to the controller.

Another 6805 controls the camera's pan, tilt, and slide motors. A third 6805 provides utility information such as battery voltage and motor temperature. In addition, that processor controls the power to the television camera and transmitter. With proper programming, the Rover could shut off its power-hungry eyes and use its other navigational information.

Not yet installed is a minimal onboard vision system to be used when the Rover is out of range of its base system. This would add one more 68000 board to the middle level.

With all these new features, Moravec's group will have a wealth of experiments to choose from as the CMU Rovers begin their active lives. The results of these experiments will, no doubt, be anxiously awaited by the many people who hope someday to be able to use autonomous mobile robots in a variety of applications.

GENERAL ARTIFICIAL INTELLIGENCE

Having the background knowledge of Moravec's experiments, we can begin to understand his statement that "mobile robots are one of the surest ways of getting at artificial intelligence." Looking at AI in retrospect, Moravec says that in the old days, people thought that "the high-level mental abilities were the hard part because people have so much trouble doing them and nothing else can do them at all."

But then "computers were programmed to solve theorems and do calculus and play chess... and, actually they did it rather well. They didn't do it as well as the very best people, but most of these things they did as well as the average person, which is not bad for a first try."

Perceptual problems turned out to be much more difficult, as Moravec's doctoral thesis and many others demonstrated. Moravec notes that when people first started to build hand-eye systems, "there were some early successes... but they very quickly bogged down." Getting a computer to see as well as the average person, according to Moravec, "is still far beyond the horizon at the moment." These difficulties in what was supposed to be the easy part of AI "led to a lot of pessimism, which we're just coming out of again."

No one, however, can accuse Moravec of pessimism. Speaking of his powerful 10-megaflop array processor (a megaflop is

one million floating-point operations per second), he says, "Personally, I think it's not powerful at all. It's just not quite so puny as the even more puny ones. I really think to do human quality vision, which is certainly what I want to do eventually, we need about 100 billion operations per second. So we're a factor of 1000 short. But we make do with what we have." Then, laughing, he continues, "I guess hummingbirds and shrews get by with less than people."

Moravec's work is one of many projects which demonstrate why the supposedly easy part of AI turned out to be difficult. But why did the supposedly difficult part turn out to be easier than expected? Moravec's theory is that for the high-level mental abilities, "the machines don't have much competition. People are not very good at them either. People haven't been doing them very long... a million years at the most, a few thousand for most of them."

"[Furthermore] we're using general-purpose mechanisms to do things for which they're not very well designed. As an extreme example, for instance, consider the capability of people to add large lists of numbers. Computers instinctively add numbers. Even the [calculator] in my pocket can do that. People are much slower. And if you look at what's probably happening in their brains, people are using tens of billions of neurons. They're visualizing the numbers and they're seeing the tables or they're hearing them. They're using billions of neurons where tens would suffice and could do a better job."

"But our vision has been developed over a period of hundreds of millions of years. If you look at the way it's connected, there are neurons connected up to do these lateral integration operators, and there are corner-finders and motion detectors. And they're wired up about as well as you could wire up neurons to do these things. And what's more, look at how much of the brain is probably wired up that efficiently. It's about 10 percent."

"I think we use [those structures] as a subroutine in a lot of our thinking. If we can map some high-level process onto one of those functions which we do well, then we start doing [that process] really well. That's why there are some people computers can't match. I believe those people have managed, usually through a lot of hard work, to tap some of this instinctive well. Even if it's not perfectly organized,

they've found some way of making a mapping that gives them some of the power that's there. But this means that some of the perceptual abilities are the hard part of AI."

Moravec, in all of that, is really talking about evolution. The most elegantly organized portions of our brains are those which have had the longest time to evolve and have had to cope with the most experiences. Those are the portions of our brains which we share with many other species, portions which are traceable back to our common ancestors. The high-level functions, some of which we share, but to a lesser extent, with only a few other species, evolved more recently.

Moravec notes that "this 99 percent of human intelligence has evolved exclusively in creatures that have a mobile way of life, and in the evolutionary record, they were mobile before their nervous systems grew." He finds the molluscs the most convincing example of this argument. "Clams have a few hundreds of neurons and don't do much. The octopus and squid are clams that basically left their shells and decided to move around. In response, presumably

to the pressures of the ecological niche in which they found themselves, they grew a large nervous system; imaging eyes totally independently evolved. It is as if evolution were just forcing them into that same direction [as mammals]."

A plant is an extreme case of immobility, and that clearly affects its evolution, notes Moravec. "A tree is extremely good at what it does, but it's not on the way to human intelligence. The reasons are obvious. I see [those reasons] working in our research as well as in the natural world. Mobility puts a great premium on generality. A general solution is much better for a mobile creature because it encounters such varying situations as it moves around in the world. Whereas a creature which lives in a fixed place has a much narrower set of problems to deal with. So the premium there is on much greater specialization. The evolutionary pressures there... do not lead, from the evidence of the natural world, in the direction of general intelligence.

"For that reason, I like working on mobile organisms and solving the day-to-day problems. I assume that evolution does

not have an idea of where it is going, but it does, day-to-day, solve its problems. ... If you're in the right niche, then you're solving the right problems, and you head that way anyway even though you don't know where it is."

Moravec's Mobile Robots, although they have a distinct goal in physical space, have a much more nebulous one in intellectual space. And as for Moravec himself, what is his ecological niche? It seems to be solving his day-to-day nitty-gritty problems, or, as he puts it, "We're really worrying right now about the lower levels. We'll build a cortex some time later."

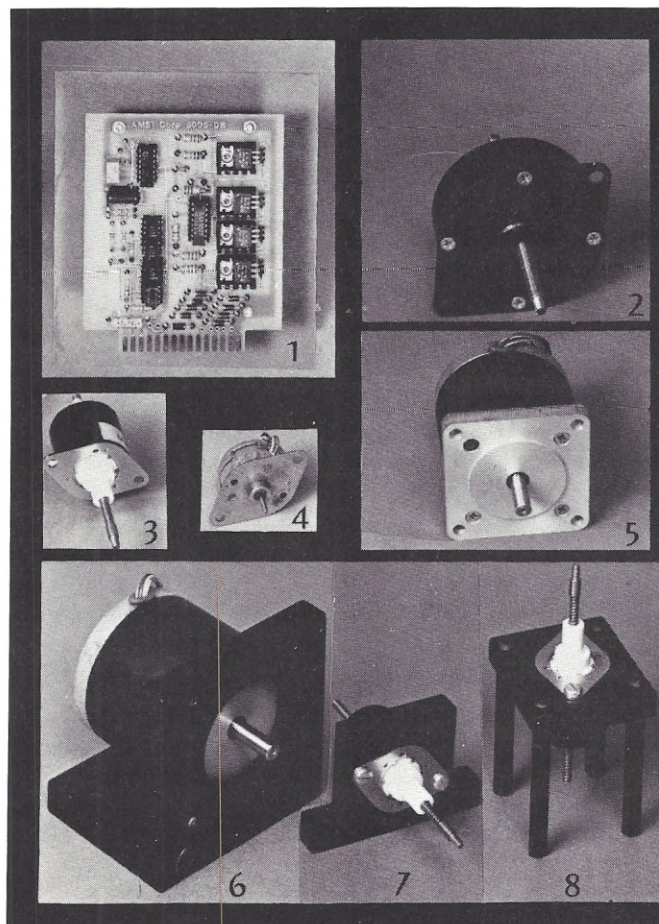
About the Author

Alfred B. Bortz is Assistant Director of the Magnetic Technology Center, Carnegie-Mellon University. He is also a freelance writer and consultant in the area of children's science books.

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ROBOTICS' ROLE IN HIGH-TECH EDUCATION

To the average person, the word *robot* engenders visions of a multi-limbed, walking, talking space odyssey... an automaton capable of performing incredible feats. In reality, educators and electronic technicians recognize the robot as a means of curing the worldwide economic slump.

Robots are already part of broad-based, high-tech educational programs. At vocational schools, robotics provides motivation and stimulation that attracts students and instructors alike. At colleges and universities, high-tech studies round out the overall development of technicians as they prepare for their careers.

Robots have ever-increasing applications in industrial and military operations. They will be used more and more in such fields as laser technology, hazardous waste management, materials use, holographic inspection, bionic-electronics, computer programming, energy, and health care. By 1990, technicians in the United States will number an estimated 2.5 million. They will need specialized training—training now offered by leaders of the robotics industry.

Robotics will help the United States narrow the disparity between its automation and that of Japan and Western Europe, a deficit that costs this country millions of dollars a day in the competitive worldwide markets that seek newer, better, less expensive goods and services.

Why robots? They can work 24 hours a day on boring tasks and in hostile environments, take no coffee breaks or vacations, seldom get sick, and do not make judgment errors. Most important, they can be easily reprogrammed to perform different tasks as required, thus making them a much more attractive investment than traditional *hard automation*. Whether viewed as friend or foe, the "iron collar worker" has found a niche in man's imagination and is an invaluable asset to man's work. Robots are here to stay. And our quest now is to understand them and use them wisely and profitably.

As U.S. industries look to robotics and

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other fields of technology as a means of economic survival, a corresponding change in America's educational system is also under way. Vocational-technical training is facing its greatest challenge, and its ability to respond will determine our economic fate. Is the challenge being met? How do we prevent "inadequate education" from occurring in existing programs?

These questions were among those raised during a recent discussion with John Lawson, the president of Feedback, Inc. of Berkeley Heights, New Jersey. Feedback has been a supplier of fundamental and leading-edge technical education equipment for more than 25 years, and is a manufacturer of educational robots.

Before commenting on the role of the robot as an educational tool, Lawson first set the stage:

"Fact: Forecasters estimate that the use of robots in manufacturing will experience an annual growth rate of 35 percent during the 1980s.

"Fact: General Motors expects to increase its number of plant robots from 300 in 1980 to 14,000 in 1990.

"Fact: The number of robots used in the United States is expected to skyrocket from 1450 in 1980 to over 21,000 by 1990.

"Fact: Major United States companies, including GM, Chrysler, Ford, General Electric, Westinghouse, and IBM have committed major capital investment to the development of increased robot applications.

"To answer the obvious question, *yes*, there is a major need to increase robotics education."

Robots have already brought significant change in such areas as improving productivity, preventing occupational hazards, and conserving resources. Recent developments in microelectronics have increased their flexibility, reliability, and adaptability so much that robot potential is virtually limitless. Tremendous potential exists in the nonmanufacturing sector, particularly in the nuclear power industry, for maintenance, repair, and the dismantling of reactors. Robots also have possible uses in ocean floor resources and coal mining.

Lawson explained that we are not pursuing robots simply because they are

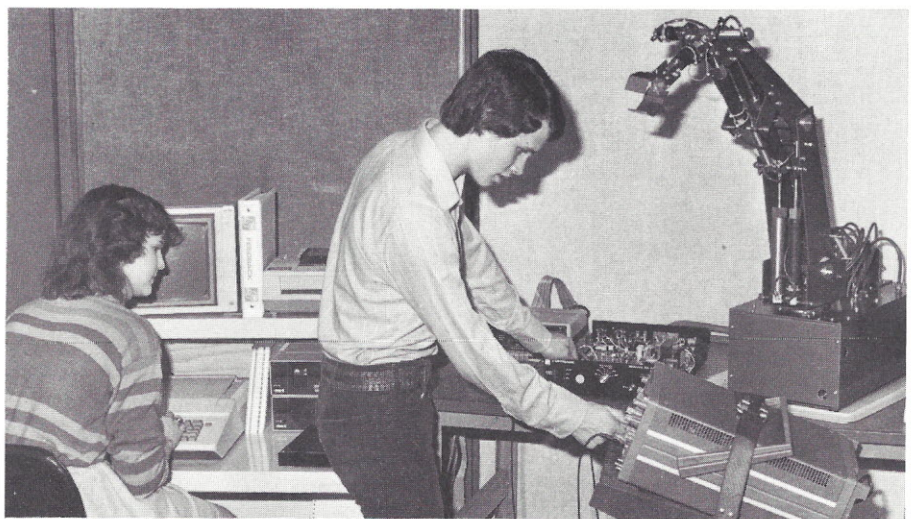


Photo 1. A typical laboratory setting showing one student controlling a Feedback Armdraulic with an Apple computer while another calibrates the robot's position transducer system.

Where the Technicians' Jobs Will Be by 1990

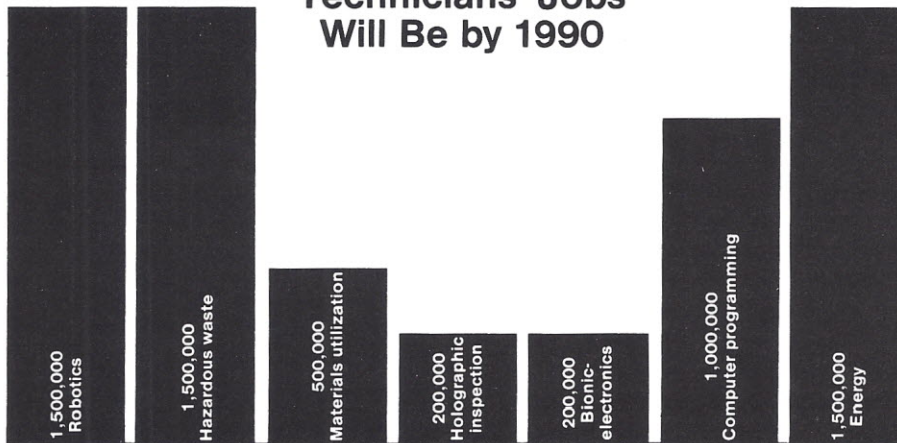


Figure 1. This chart estimates where the technicians' jobs will be by the year 1990 and the various industries served. Note the tremendous potential in the area of robotics.

futuristic or glamorous. Robots provide the essential link that makes flexible manufacturing and the "factory of the future" a feasible concept.

"But, high technology and automation do not necessarily mean that machines will replace workers," Lawson emphasized. "They do mean, however, that the role of workers will change drastically. For every new robot placed into service, an educational need is created. Keeping these robots running will require properly trained robotics engineers, technicians, maintenance, and repair people. Educational institutions must move quickly and carefully toward restructuring curricula, retraining faculty, and redesigning laboratories."

The complex systems surrounding high-tech equipment may be composed of mechanical, electrical, electronic, hydraulic, and pneumatic devices, just to name a few. A broad base of knowledge and an understanding of basic principles in the various practices of high technology will be needed to give technicians the required flexibility. And, while the need for specialists in all of these important areas will always exist, the greatest need will be for the "super-tech," able to operate, maintain, and repair systems that incorporate combinations of mechanisms, hydraulic actuators, digital circuits, electric motors, and the like.

About 30 universities and colleges in the United States offer full degrees in robotics education, and the number is growing steadily. More vocational-technical schools, junior colleges, and universities are adding robots and robot courses to their curricula. The government is making available mil-

lions of dollars to further high-tech education, with a particular emphasis on robotics. On the surface, the future looks bright.

One problem may be ahead. Although robots are exciting and outstanding enrollment builders, many schools have no idea what to do with a robot once they have it. Many of the educators asked to instruct a robotics course may be inadequately

trained to do so. Some programs may even produce "robot specialists" who lack a well-rounded background or who are incapable of adapting to changes in technology.

A well-designed curriculum prepares technicians for robotics as well as other high-tech occupations. The emphasis should be on practical applications and real-world examples. Yet, once the student has reached a certain level of ease and competence, studies should be made available in specialized fields such as robotics, microelectronics, lasers, or newly developed fields.

"The robot... can stimulate and motivate a classroom like no other high-tech teaching tool and can transform textbook theory into exciting, practical, hands-on experience," Lawson explained. He outlined criteria educators should consider when selecting an educational robot:

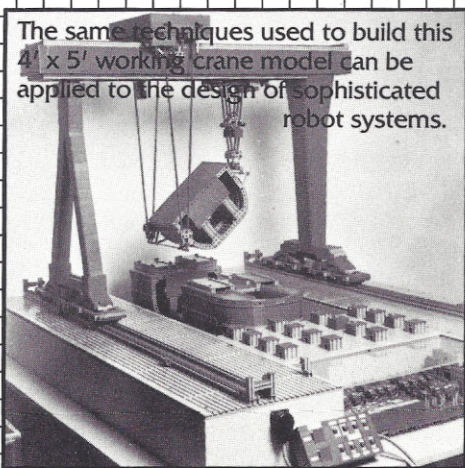
Credibility—The mechanism should closely resemble a useful robot and must possess capabilities with obvious industrial relevance. These factors are not only essential to student motivation, they also aid the school in its quest for funding. Beware of robots that are great attention-getters on open-house day but have limited practical teaching potential.

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Flexibility—The key to any robot's success is its flexibility. An educational robot should be able to adapt to different teach-

ing roles (serving versus programming, use with different host computers for off-line programming, and so on).

Technology—The equipment must exemplify desirable design features of its type. The most generally accepted robot device is the revolute arm of five closed loop axes plus a gripper. It should be programmable by walk-through techniques, teach pendant, and external host computer.

Safety—The robot should be designed so it does not injure students and is not easily damaged.

Extendability—The robot should be easily modified for local project work (fitting of custom-designed end-of-arm tools, mounting of vision systems, and so on).

Support—Educators should select a supplier willing and able to provide readily available training, applications assistance, and service.

By paying attention to these requirements and carefully selecting robot vendors, educators can create a useful learning environment.

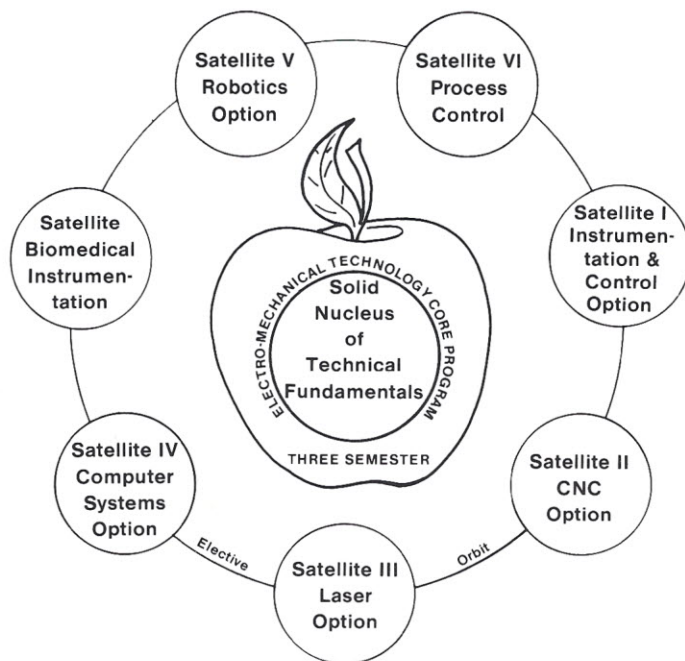


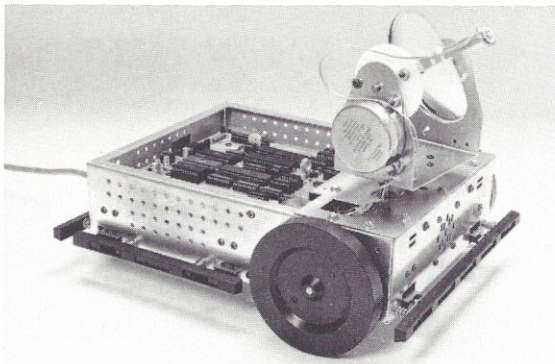
Figure 2. The Feedback Nucleate Program Concept gives students a broad knowledge base and an understanding of basic principles. The program consists of two parts, an electromechanical technology core and specialty satellites. The core concentrates on the various area that govern high-tech occupations such as fluids, mechanics, computers, etc. This type of core program forms a firm foundation for all high-tech fields and provides a necessary knowledge base.

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USING THE POLAROID ULTRASONIC RANGING SYSTEM

When I first considered creating a synthetic mobile intelligence, it became quickly obvious that the most important decision would be the creation (or selection) of the sensory apparatus. The choice of hardware at this point profoundly influences the device complexity and the ultimate achievable intelligence.

There is an unfortunate relationship between sensory complexity, data quality, and speed. Systems providing the highest quality data are the most complex and difficult to interpret. Difficulty, in this case, relates inversely to speed.

Another factor is the device's structure. For my machine, I felt that limiting the robot's vertical stature would limit its needs for perception. World modeling might then realistically be limited to the two principal

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axes of the robot's existence. In this way, all navigational considerations are reduced to the supporting plane and its perimeter walls. It was this decision, in addition to low cost and electronic simplicity, that made ultrasonics the obvious choice.

A search of then-current literature led to the discovery of Tod Loufburrow's book, *How To Build a Computer-Controlled Robot*. Here I found the plans for an LM1812-based ultrasonic transceiver. This device uses a piezoelectric crystal which "rings" at its natural resonant frequency when "pumped" with a high-voltage pulse. I built the transceiver, but its ranging and

resolution were severely limited by the transducer sensitivity.

THE POLAROID SYSTEM

Abandoning piezoelectrics was easy when I discovered the marvelous electrostatic unit marketed by the Polaroid Corporation. I tried one, and its performance was spectacular. The system consists of an electrostatic transducer and two printed circuit cards. The smaller of the two cards contains the transducer drive and echo-detection circuitry; the larger contains the multiple-drive logic which controls the firing rate of the smaller board. The larger board also keeps track of the time interval between transmission and echo detection, which it displays as distance in feet on an LED display.

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Any interface to this device must provide for two things: the initial firing of the transmitter and the measurement of the period between transmission and echo detection. My investigations led to two different ways of meeting these requirements, different in both the resolution of the data they acquire and in the amount of hardware required for the interface.

The simplest approach uses two interrupts and the period of the main program loop for timing the transmit-echo interval. If interrupts are not available in your system, input/output (I/O) ports and polling may be substituted with only a marginal loss of accuracy.

interrupt reads and stores the value in the software counter.

Each transmit cycle spans a period of 200 ms, which is divided into 100 ms of transmitter *on* time (beginning when VSW is driven high) and 100 ms of drive circuit bleed-down time. You can reduce the bleed-down period to 40 ms by adding the 1000k Ohm resistor shown in the dotted circle of Figure 2.

At the conclusion of each transmit cycle, VSW is driven high, the software counter is reset to zero, and the whole process repeats. Using this approach, resolution is limited primarily by the period of the software counter.

For low cost and high reliability, my personal philosophy always dictates the substitution of hardware with software wherever possible. While this approach is acceptable for many applications, my machine's growing need for greater precision forced the development of a second, more hardware-intensive interface. The

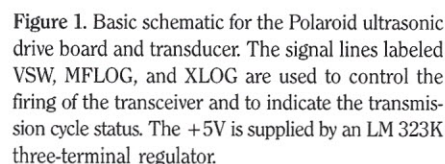


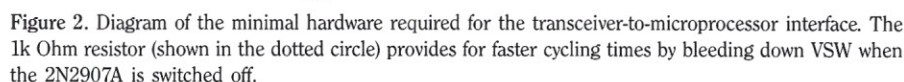
Figure 1. Basic schematic for the Polaroid ultrasonic drive board and transducer. The signal lines labeled VSW, MFLOG, and XLOG are used to control the firing of the transceiver and to indicate the transmission cycle status. The +5V is supplied by an LM 323K three-terminal regulator.

second design dramatically improved resolution while simultaneously reducing software overhead.

The hardware in Figure 2 includes a 7473 JK flip/flop (the low-power Schottky version does not work) and an Intel 8253 programmable three-channel timer. Prior to operation, this device requires an initializing sequence which proceeds by writing the zero mode word and a count of five to the timer and then allowing it to time out. This causes the OUT pin to go high, driving Q low and gating the timer off. Beginning each transmit cycle, the mode and count words are again written to the 8253, and VSW is driven high by the 4801 latch driver acting through the 2N2907A transistor. At this point, system setup is complete and the program may resume normal subroutine service.

When transmission begins, the inverted XLOG signal pulls J high, thus driving Q high and allowing the counter to begin counting down. When or if the echo returns, the inverted MFLOG signal pulls K high, driving Q low, disabling counting. The count data remains latched into the 8253 until the end of each transmit cycle. At that time, the count data is read from the timer into a memory storage register, where it remains until it is updated at the conclusion of the next transmit cycle.

When using a 750 kHz timer clock and with the transceiver looking at fixed objects ranging from six inches to ten feet, this system has demonstrated a repeatability of plus or minus two clock cycles. Since this device transmits at four frequencies ranging from 50 to 60 kHz, a 750 kHz timer clock yields about 12 clock cycles per transmitted wavefront. At this frequency,



the observed repeatability of four clock cycles (one third of a wave) is equal to about 0.072 in. (Sound at standard temperature and pressure travels at 1086 feet per second. The length of one wave is therefore equal to 1086 fps divided by 60 kHz). Transmitting at higher frequencies would improve resolution, but would sacrifice range because of attenuation.

The manner in which this system is used is crucial to its efficiency. The optimal arrangement requires running the transmit-receive-store cycle continuously. In this way, range data, updated at regular intervals, is available to any program module requiring it.

PROBLEMS AND SOLUTIONS

I found a potential error mode in this system which mysteriously never occurred. If the echo does not return, Q is never driven low, the timer remains gated on, and counting begins as soon as the next count word is loaded instead of waiting until transmission begins. For its own reasons, Polaroid has taken care of this problem using the generation of a so-called *synthetic infinity*. The Polaroid board is designed so that if there is no echo return, MFLOG

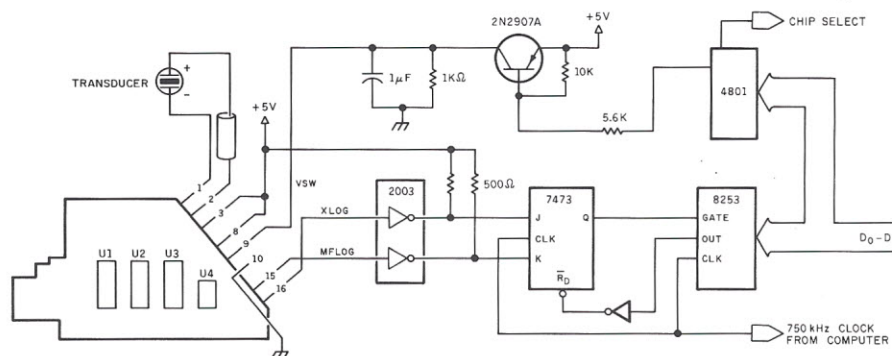


Figure 3. High-speed, high-resolution interface to the Polaroid drive board. The inverted signal from the timer's OUT pin stabilizes the loaded count until the XLOG transition gates the timer on.

automatically goes low 75 ms after transmission, thus gating the timer off and ensuring correct transmitter sequencing.

One other problem area is the transceiver's sensitivity. MFLOG may occasionally record an echo return immediately following transmission. This may be handled either by adjusting the sensitivity potentiometer on the Polaroid board or by assuming an immediately returned pulse is erroneous. Sensitivity adjustments may be simplified if you have an oscilloscope. While monitoring the Q output of the 7473 counter, the adjustment potentiometer should be rotated from full clockwise (max-

imum sensitivity) to full counterclockwise (minimum sensitivity), causing the transceiver to range from frequent false triggering, through a band of consistent accurate echo detection, to a cutoff point where no echoes are received. The potentiometer should be adjusted to the region of greatest repeatability when the transducer is focused on a fixed object.

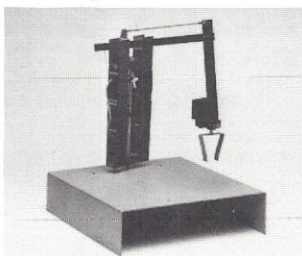
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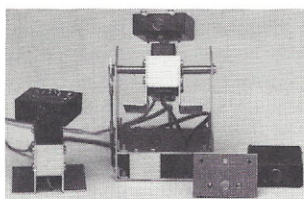
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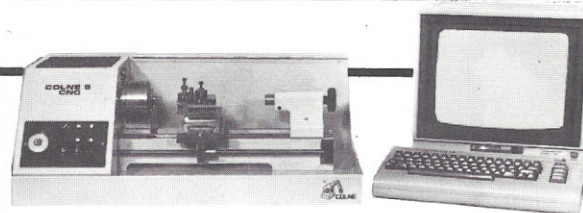
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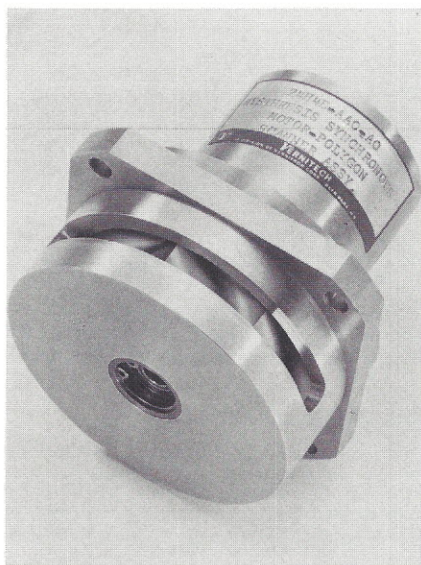
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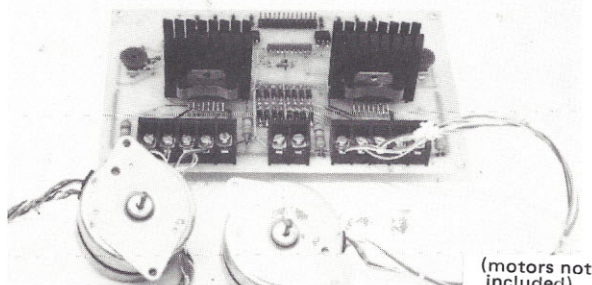
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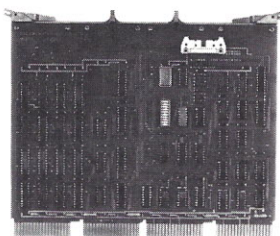
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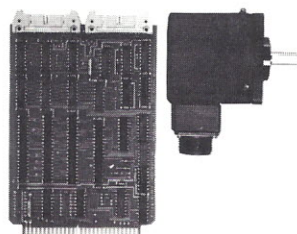
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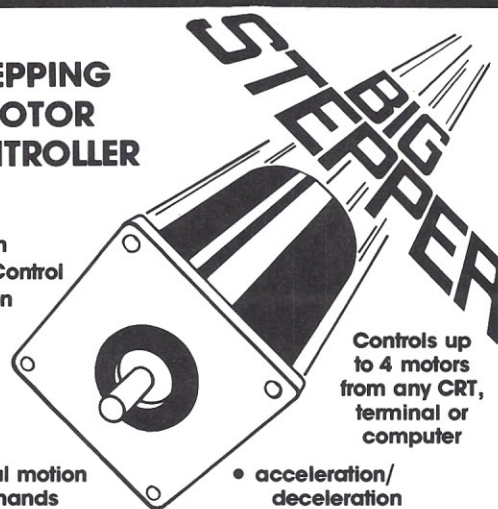
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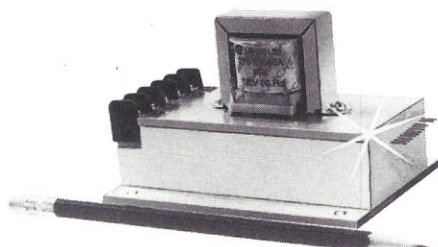
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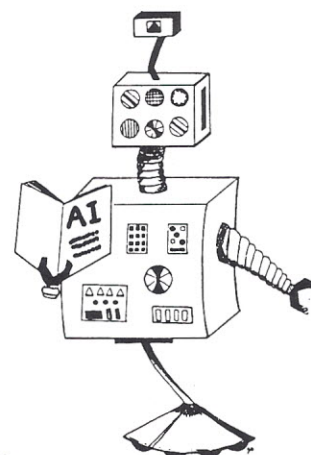
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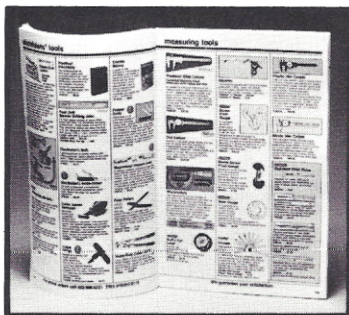
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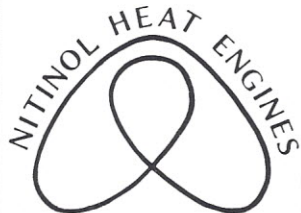
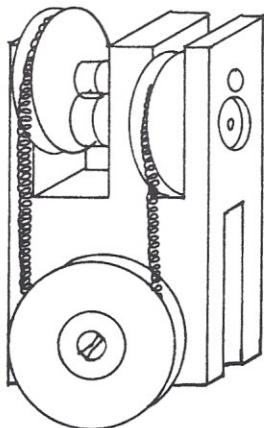
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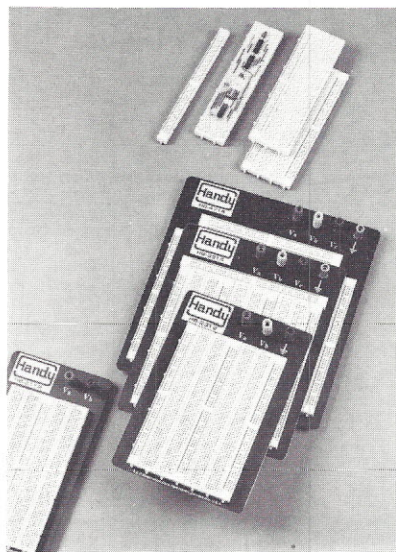
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New Products



Handy Helpers

Handy Products offers a line of eight low-cost, high-quality solderless breadboarding devices designed specifically for computer software and hardware test and circuit building. The basic HB-0100 Bus Strips contain four groups of labeled contact points (25 per group), providing multi-point distribution for power, ground, and signal paths. The Handy line includes four mounted board configurations. Model HB-2112 features two sockets, one bus strip, and two binding posts on an 8.7 by 5.4 inch aluminum ground plate with 18, 14-pin DIP binding posts. Model Model HB-2313 includes two sockets, three bus strips, and three binding posts; while HB-3514 offers three sockets, five bus strips, and four binding posts to allow up to 27 14-pin DIP chips. The largest, Model HB-4714, includes four sockets, seven bus strips, and four binding posts to support 37 14-pin DIP chips. Each array is mounted on heavy aluminum ground plates with rounded corners and rubber feet to protect work surfaces.

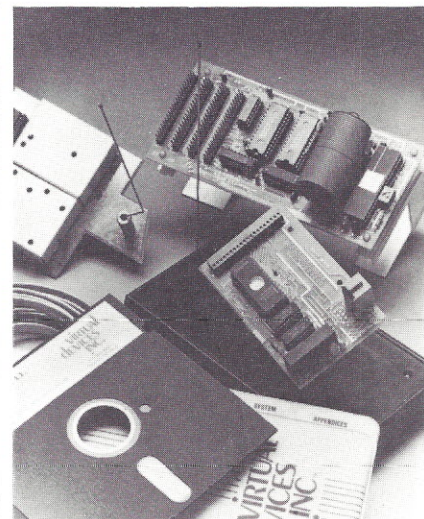
All products are in-stock and available for off-the-shelf delivery. Quoted prices claim to be up to 25 percent lower than comparable breadboarding products. A complete, illustrated catalog is available by contacting RSP Electronics Corp, Handy Products Division, 7 Business Park Drive, PO Box 699, Branford, CT 06405, telephone (800) 34-HANDY. Connecticut, Alaska, and Hawaii call (203) 488-6603. Circle 50

Robot Operating System

The Menos I System enhances the usability and function of a Hero I robot, especially with regard to educational and training applications. Consisting of both hardware and software, Menos I allows the user to program a robot in conjunction with a personal computer. A high-level computer language specifically developed for use with Menos I permits a previously unattainable speed and efficiency in programming robotic tasks. The robot and personal computer communicate via an error-corrected, two-way digital radio system, providing both immediate execution and remote programming commands.

Menos I allows the experimenter to write complicated programs on a personal computer using familiar procedures, then download to the robot and communicate with it while the program is in progress. The system even allows the user to see the motor positions and sensor readings while the robot is moving. There's no need to tediously key commands directly into the robot.

The Menos I system also offers a simulation mode, in which the computer screen reflects exactly what the robot is doing at each step in the program. The programmer can use Menos I to write robot programs,



test them in simulation mode, then store them for use with the actual robot.

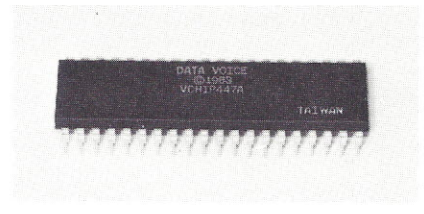
The Menos I System comes complete with software, a remote computer for the robot, and all necessary hardware, as well as a complete and comprehensive user's manual. The price is \$795 with radios included or \$595 with a cable link.

For further information, contact: Virtual Devices, Inc., 4801 Montgomery Lane, Suite 116, Bethesda, MD 20814, telephone (800) 762-7626 or (301) 986-9327. Circle 51

Single-Chip Synthesizer

The Voice-Chip™ speech synthesizer is a single, 40-pin chip that requires no external controller or address encoder—both are internal. The Voice-Chip uses the DataVoice encoding process that assures high-quality voice reproduction with little filtering. Up to 16 seconds of speech in male or female voice can be reproduced. Four inputs are used for activating speech, and they can be driven with TTL signal levels, or connected to ground with simple switch contacts. Single utterances and continuous repeats may be generated.

Voice-Chip will scan inputs on either a priority or a rotating basis. Scanning stops when a message has been activated and resumes at its completion. Pauses and timing delays are programmable. A special input configuration is available: one input is used to activate speech, while the remaining three are used as addresses to select from a maximum of eight varying-length



messages. No external logic is needed to operate the memories. Signals are supplied by Voice-Chip, and speech look-up table is included in memory to let Voice-Chip know which words and phrases to say. Voice-Chip operates in a range from 4.5 V to 6.8 V.

A Voice-Chip demonstrator can be purchased through DataVoice and its distributors. The demonstrator includes a printed-circuit board, the Voice-Chip, two EPROMs with sample vocabulary, an amplifier, speaker, and input keypad.

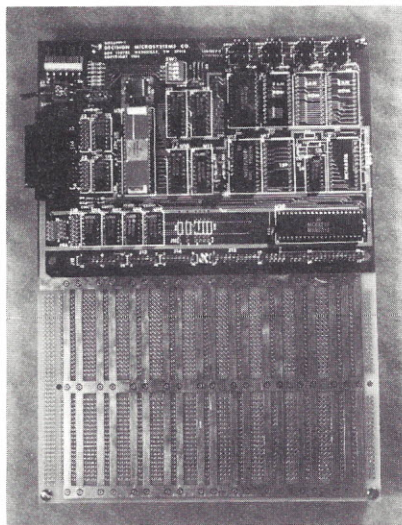
For more information, contact: Rick Arons, DataVoice Corp., 2 N. LaSalle St., Suite 1900, Chicago, IL 60602, telephone (312) 831-4488. Circle 52

New Products

6801 Microprocessor Development Aid

The DMS6801-1 is a Motorola MC-6801LI-1 microprocessor-based prototype development board providing engineers, experimenters, and students with a low-cost and versatile system to build and test small-to-medium-sized microprocessor applications without the need for expensive card cages or development systems. All of this is accomplished by providing a generous breadboard development area supported by a resident monitor and logic circuitry specifically conceived to ease interfacing the microcomputer to the user development area. For example, very little, if any, additional logic is needed to add more memory and peripheral devices. If the user desires a minimal system, a TTL-level power supply is all that is necessary. If RS-232 communication facilities are desired, ± 12 V is required.

The DMS6801-1 features a Motorola MC-6801LI-1 8-bit microcomputer and consumes less than 3.5 W. Standard serial communication rates of 300, 1200, or 9600 bps are selectable. RS-232 compatible signals are available at an edge-mounted DB25S connector. All of the board's timing and control signals, including reset, are buffered. Circuitry is provided to demultiplex and buffer the address for a full 16 bits. The full 64 Kbytes of address space is fully decoded into 32 2-Kbyte segments. A segment of the lowest 2-Kbyte memory space is further decoded to provide eight 4-byte wide peripheral



al select lines and one 64-byte wide select line. Additional circuitry provides room for more memory, an MC6821P Peripheral Interface, space for a clock/calendar, and an 8.15 by 5.40 in. prototyping area. The DMS6801-1 comes with a manual that contains complete board details, an overview of the MC6801LI-1 features, user component installation guide, and references to other useful MC6801 information and application sources. A Motorola publication describing the LILbug monitor is also included.

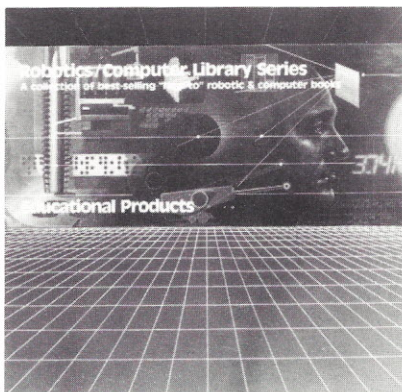
The DMS6801-1 microcomputer prototype board is available for \$320 for commercial buyers and \$225 for academic institutions from Decision MicroSystems Co., PO Box 120783, Nashville, TN 37212.

Circle 53

Educational Products Catalog

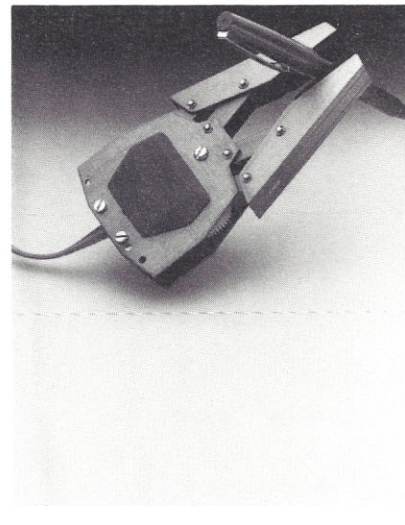
Educational Products offers a specialized collection of 47 best-selling how-to electronics books and 17 software program diskettes on robotics and personal computers. Catalog titles include *Handbook of Advanced Robotics*, *Robots and Robotology*, *How to Design and Build Your Own Custom Robot*, *Robot Intelligence With Experiments*, *The Home Machinist's Handbook*, and *Microprocessor Interfacing*. Specialized computer books are offered for every major personal computer.

The Robotics and Personal Computer Books catalog (EP-884), is available free



upon request from Educational Products, PO Box 606, Mineola, NY 11501.

Circle 54



Robot Gripper

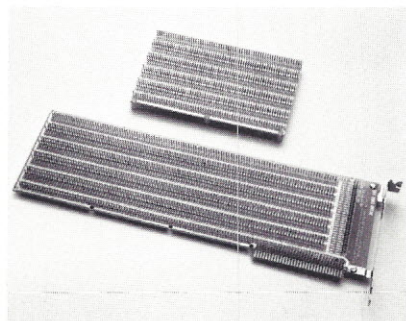
A robotics gripper designed for education, research, and light industrial applications has been introduced by Cybot, Inc. The Cybot Gripper has a 0 to 2 in. grip range and a large squeeze force-to-weight ratio, weighs only 6 ounces, and has a squeeze force of 10 pounds. The jaw position can be sensed by forward and reverse limit switches. Outputs are also provided to sense jaw position and force. The gripper's electromechanical system uses a samarium-cobalt DC motor which provides extremely high torque in a lightweight package. The short electrical time constant of the motor enables it to be used with efficient pulse-width modulation drives. Conventional linear drives can also be used and will not have to supply more than 100 mA of current.

Mounting the Cybot Gripper to robotic arms is relatively easy. Two methods are provided. A universal mount with four through-tapped holes makes connection to sheet metal arms easy. Similarly, a clamp is provided to attach the gripper to a 0.5 in. shaft. An 18 in. cable and connector provides power to the DC motor and outputs for sensing gripper position and force.

Connecting the Cybot Gripper to a computer does not require extensive hardware design. Because of low power requirements, the gripper can be driven with the power directly available from most computers.

The Cybot Gripper is priced at \$249.95. For more information, contact: Cybot, Inc., 733 7th Ave., Kirkland, WA 98033, telephone (206) 827-6199. Circle 55

New Products

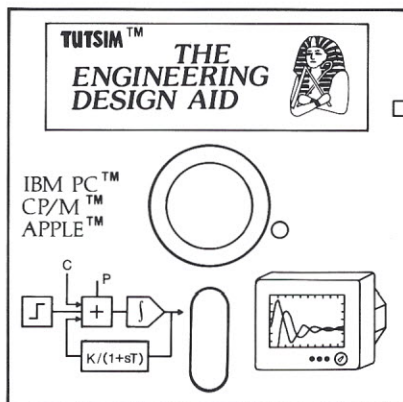


IBM PC Prototype Board

The Model PC100 is an IBM PC/XT compatible prototype board with two-level wire wrap pins on the component side. The high-density configuration uses no more space than a printed circuit board and permits mounting on 0.500 in. slot spacing. The PC100 accepts ICs with 0.300, 0.600, and 0.900 in. pin centers. Extensive power and ground planes with uncommitted wire-wrap pins provide adjacent access to all ICs and other components. Sixty IO holes for right-angle D-subminiature connectors are provided. For additional circuit capacity, plug-in piggyback boards are available in four different lengths. A full-size layout sheet is included to simplify component placement.

The PC100 is available for \$59 from Intercon, Inc., 11 Charlam Drive, Braintree, MA 02184, telephone (617) 848-9656.

Circle 56



Tutsim Evaluator

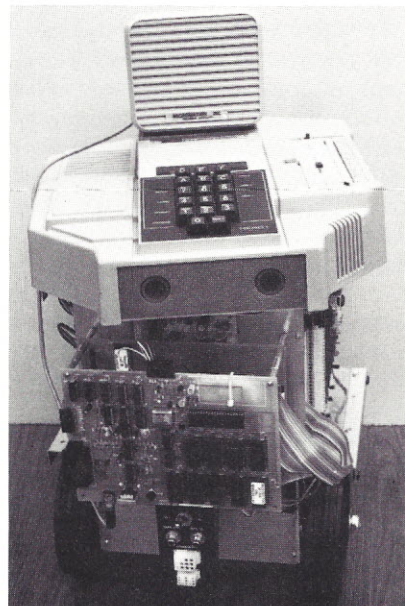
TUTSIM, a program for simulation of continuous dynamic systems, is now available in a short form suitable for evaluation, demonstration, and instructional study. The professional version of TUTSIM for microcomputers handles up to 999 blocks. The short form TUTSIM has the same syntax, the same manual, an extended set of examples on disk, and all other features of the professional version, but is limited to ten blocks.

TUTSIM is available for the IBM PC/XT and PC Jr. Other versions are available for the Apple II and selected CP/M machines. The professional version of TUTSIM sells for \$475 to \$525, the short form retails for \$29.95.

For more information, contact: Applied i, 200 California Ave. #214, Palo Alto, CA 94306, telephone (415) 325-4800.

Circle 57

Robot Speech Command System



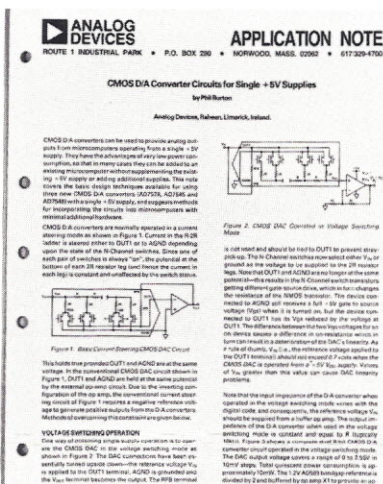
VOREC, a microprocessor controlled speech recognition board for the Heath Hero I, provides recognition accuracy of up to 256 words. Words are stored as 16 word groups with 16 words in each group. The 256 words are stored in 14 Kbytes of onboard programmable memory. A battery backup allows the Vorec board to retain word parameters when the robot is shut off. High-speed CMOS chips and the new CMOS 6502 microprocessor consume only 45 mA while active and 1 mA when inactive.

Speech recognition is accomplished by a software algorithm contained in a 2 Kbyte EPROM. An external speaker is used for the audio input, allowing the robot to receive commands from up to 15 feet away. A high-level language software package called Vocol supports both immediate and deferred execution modes for the robot. Following a voice training session conducted by the robot, you can speak a set of programmed moves or command immediate moves. The Vorec board has an RS-232 serial port for receiving and transmitting commands and data to the host robot. Vorec is compatible with all personal computers.

For more information, contact Micromation, Inc., 9104 Red Branch Rd., Columbia, MD 21045, telephone (301) 730-1237.

Circle 59

CMOS D/A Application Note



Analog Devices offers a free application note describing the use of CMOS digital to analog converters in microprocessor-based systems. The application note details circuit techniques available to the designer when only a single +5V power supply is available. Specific topics of discussion include single-supply operation of CMOS digital to analog converters in the voltage-switching or current-switching mode of operation, selection of amplifiers for single +5V operation, and interfacing single +5V supply digital to analog converters to microprocessors.

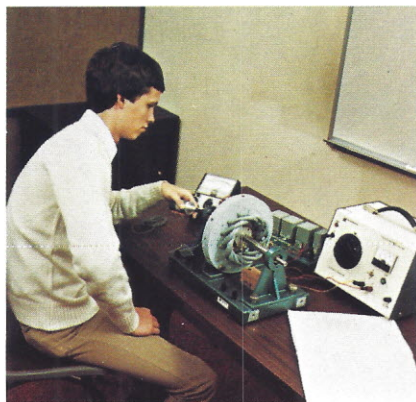
For more information, contact: Analog Devices, Route 1 Industrial Park, PO Box 820, Norwood, MA 02062.

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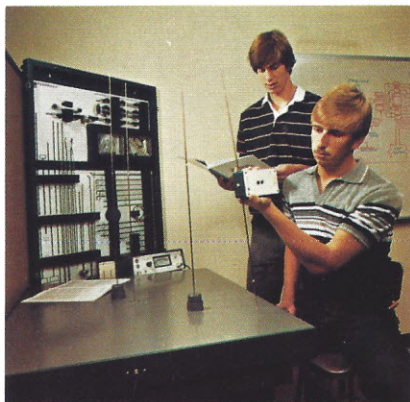
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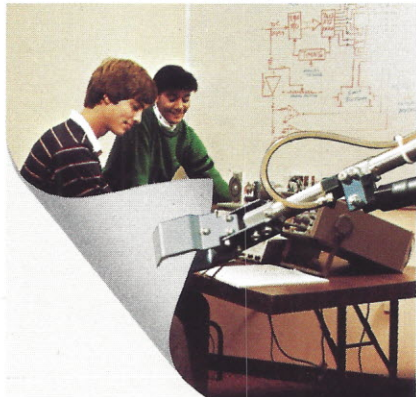
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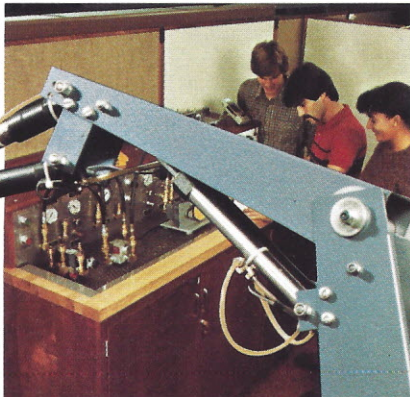
Electronics & Electricity



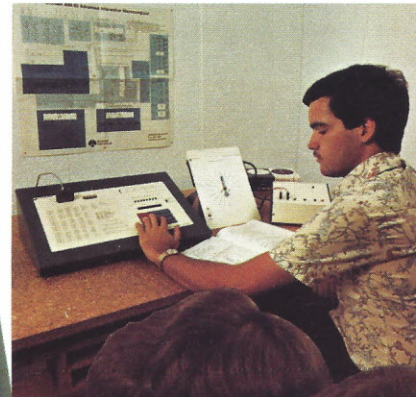
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